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Kong et al.

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(54) **THREE-DIMENSIONAL MEMORY DEVICES WITH SUPPORTING STRUCTURE FOR STAIRCASE REGION AND SPACER STRUCTURE FOR CONTACT STRUCTURE AND METHODS FOR FORMING THE SAME**

(58) **Field of Classification Search**
CPC H10B 43/27; H10B 41/10; H10B 41/27; H10B 43/10; H10B 43/40; H10B 43/50; H10B 43/35
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 893 days.

This patent is subject to a terminal disclaimer.

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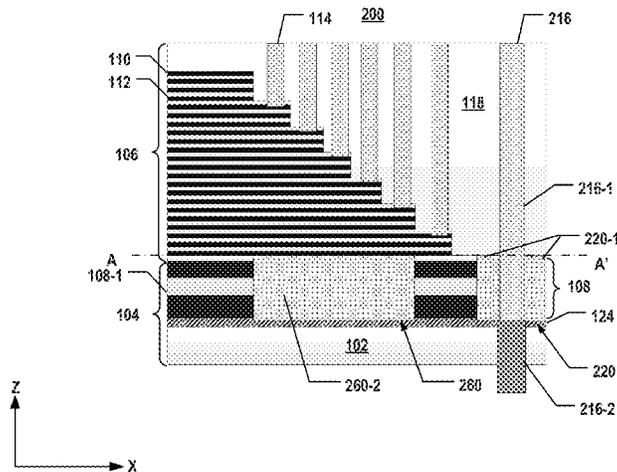
(52) **U.S. Cl.**

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(57) **ABSTRACT**

Embodiments of 3D memory devices and methods for forming the same are disclosed. In an example, a 3D memory device includes a memory stack, a semiconductor layer, a supporting structure, a spacer structure, and a contact structure. The memory stack includes interleaved conductive layers and dielectric layers and includes a staircase region in a plan view. The semiconductor layer is in contact with the memory stack. The supporting structure overlaps the staircase region of the memory stack and is coplanar with the semiconductor layer. The supporting structure includes a material other than a material of the semiconductor layer. The spacer structure is outside the memory stack and is coplanar with the supporting structure and the semiconduc-

(Continued)



tor layer. The contact structure extends vertically and is surrounded by the spacer structure.

19 Claims, 17 Drawing Sheets

- (51) **Int. Cl.**
H10B 41/27 (2023.01)
H10B 43/10 (2023.01)

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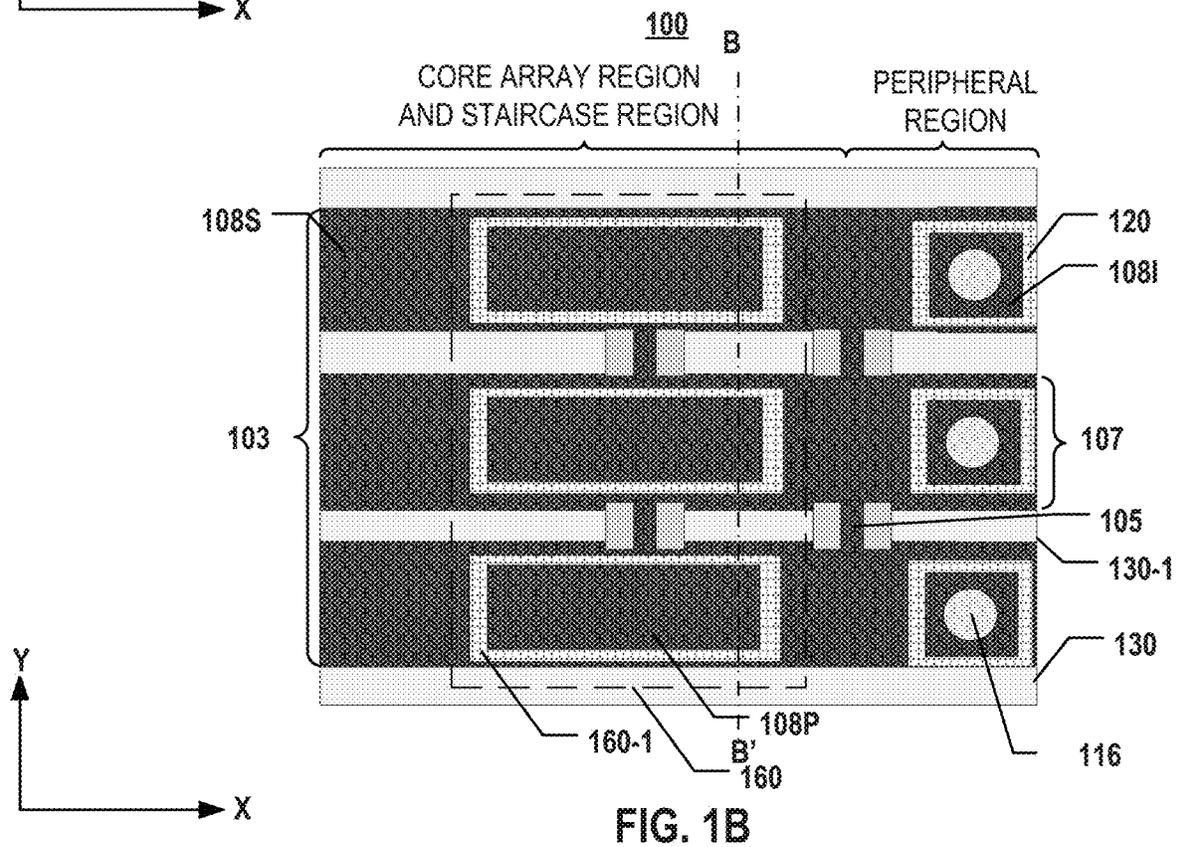
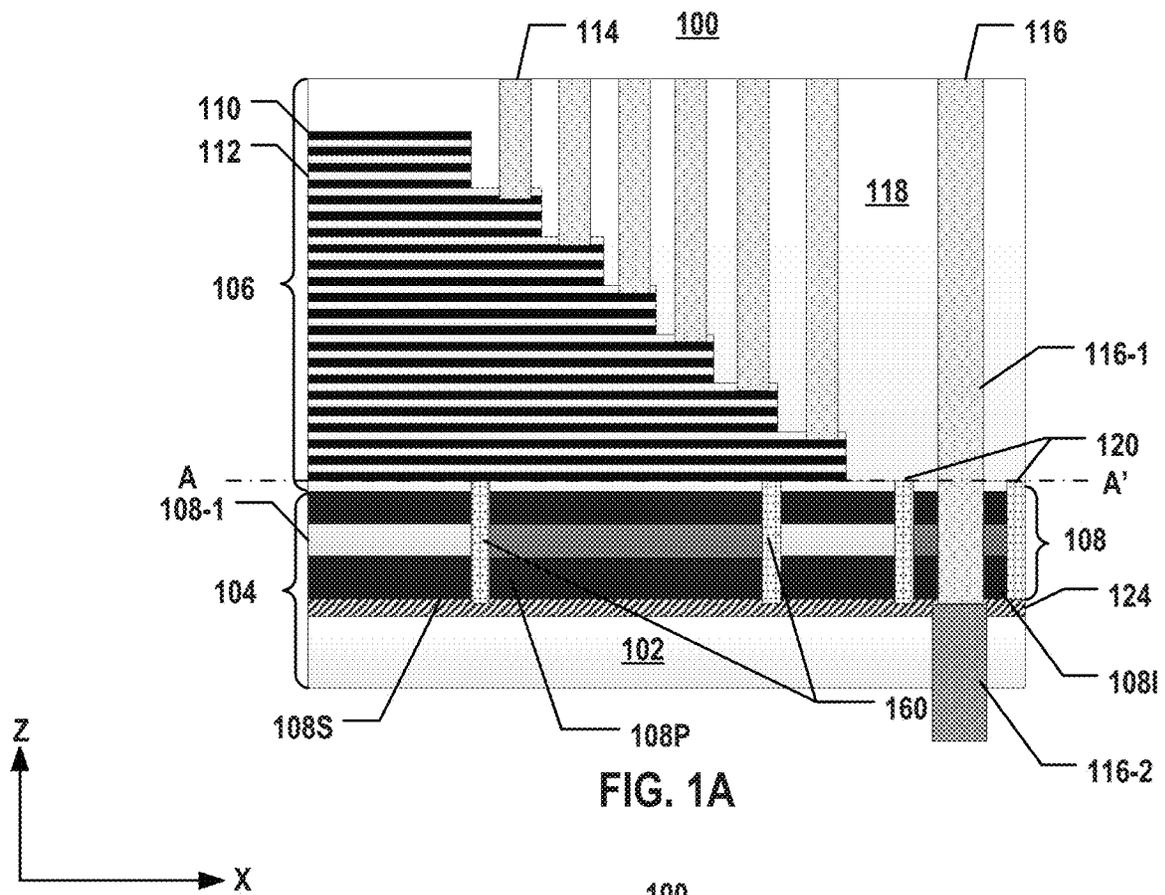
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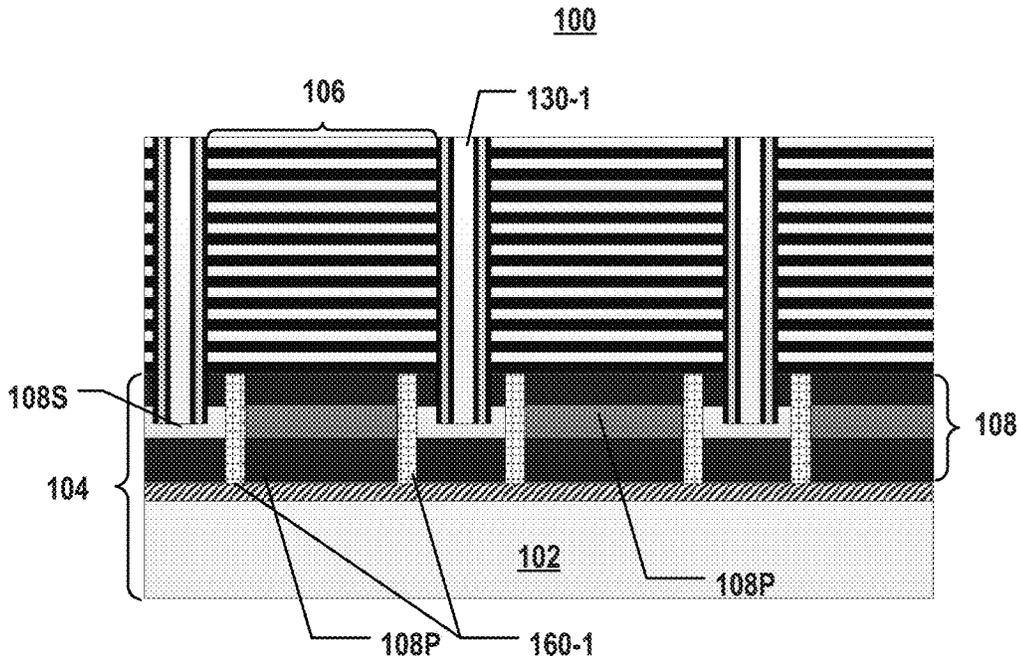
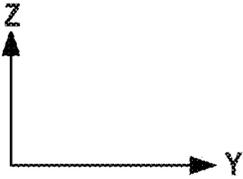
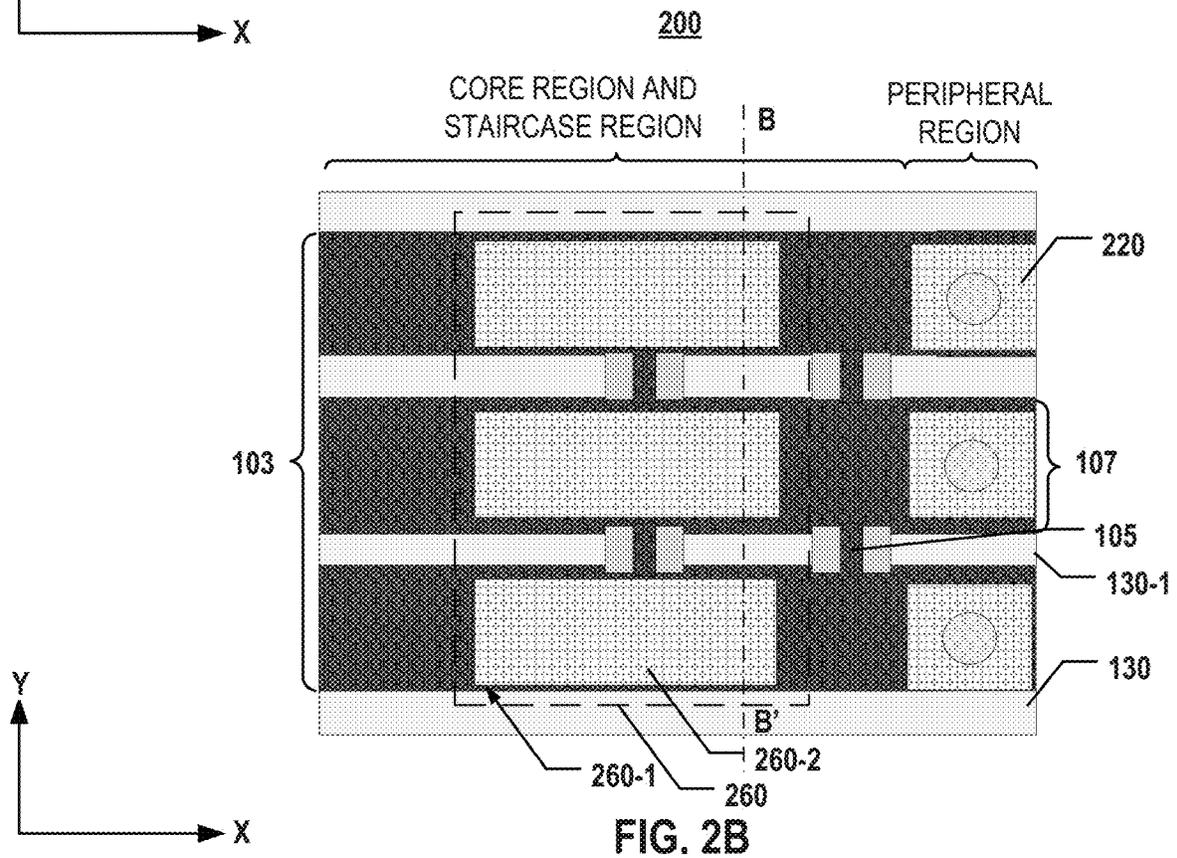
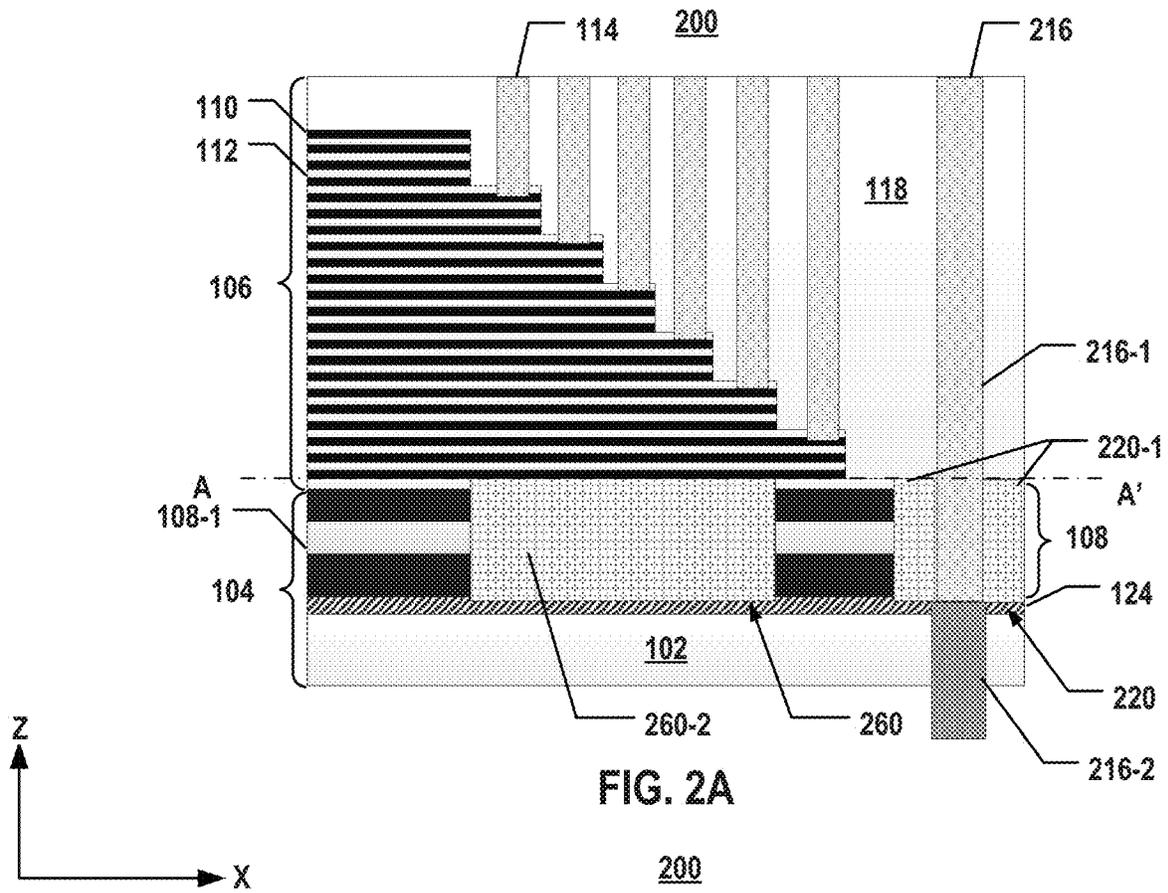


FIG. 1C





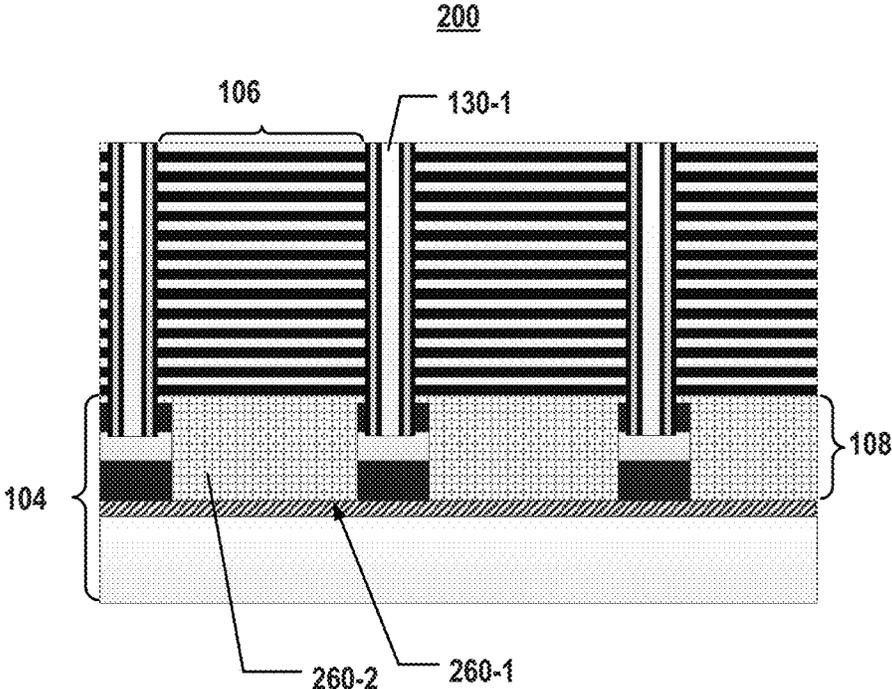


FIG. 2C



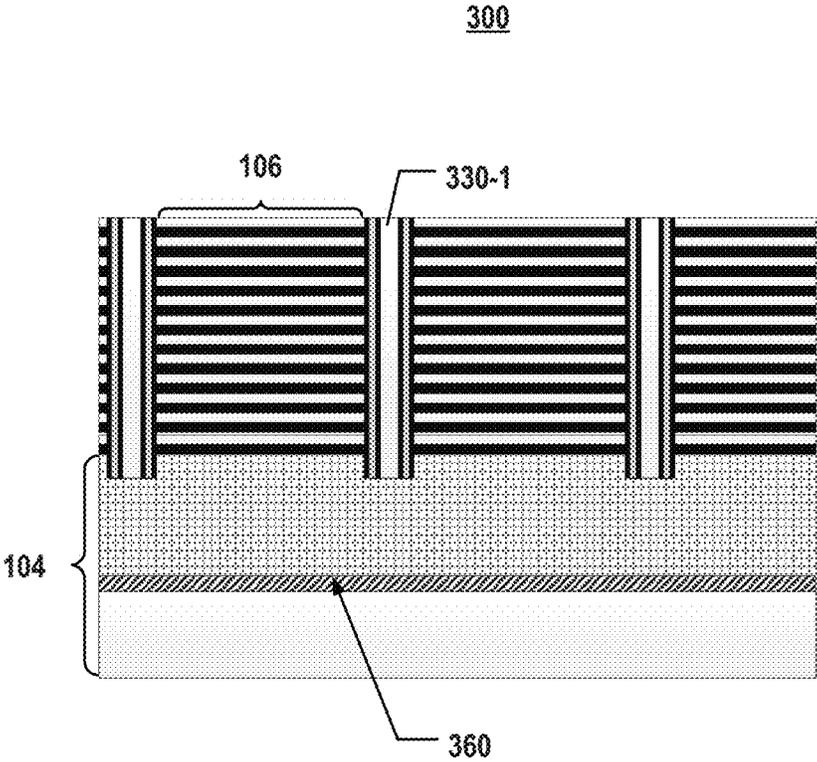
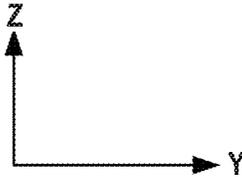


FIG. 3C



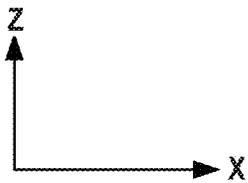
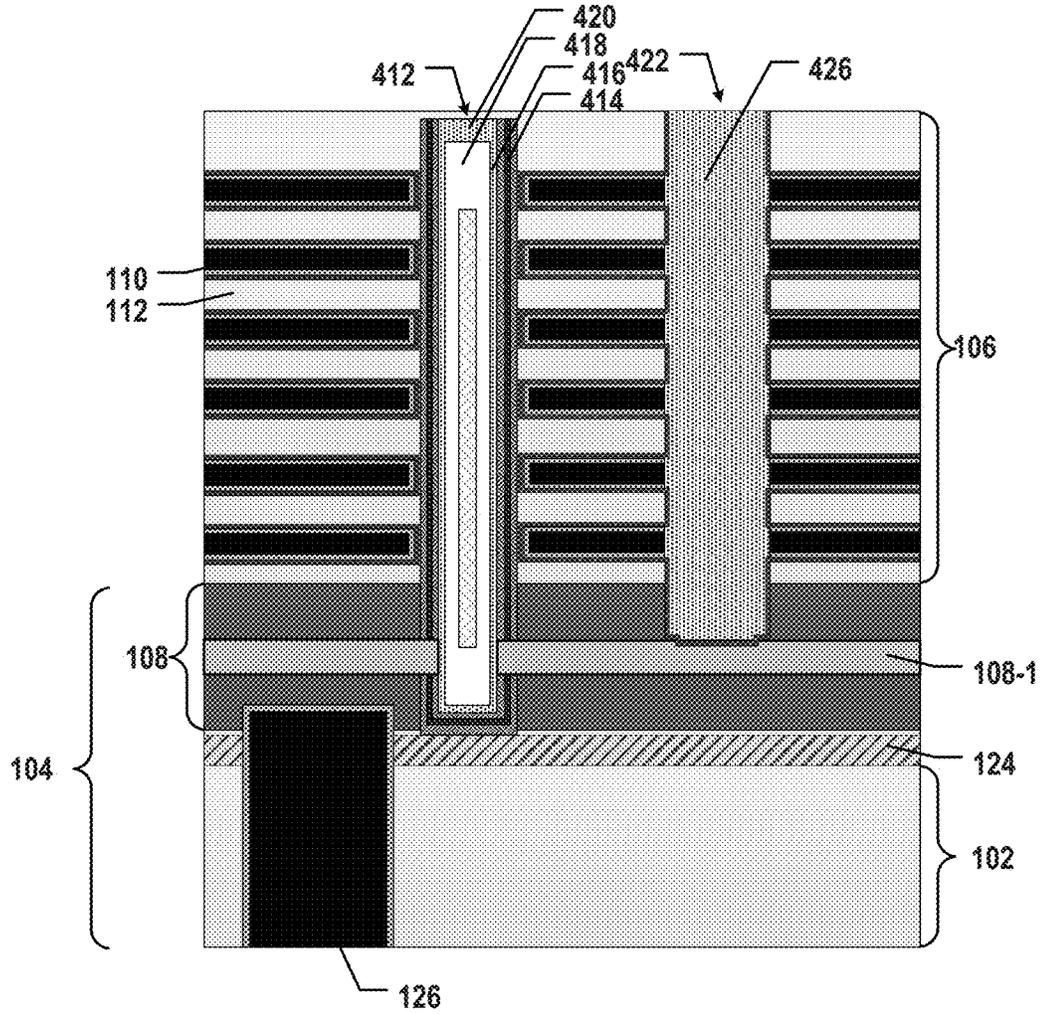


FIG. 4

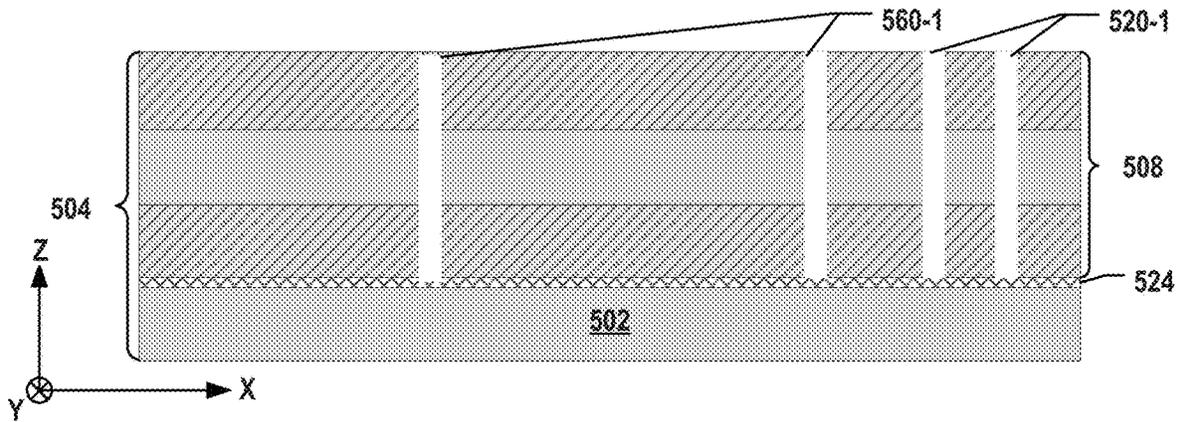


FIG. 5A

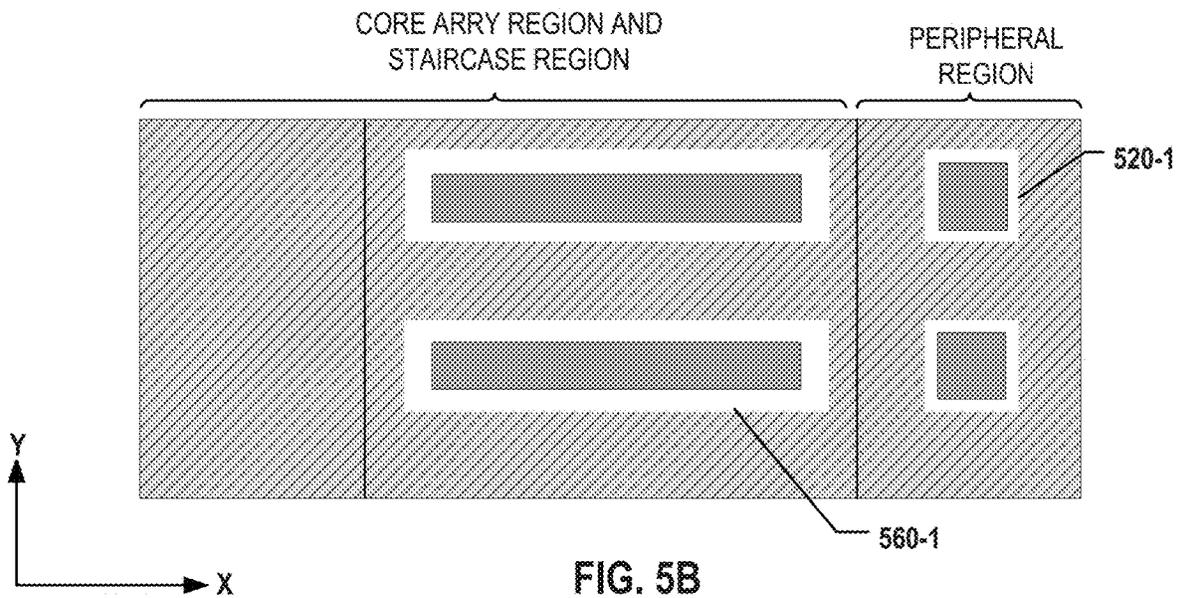


FIG. 5B

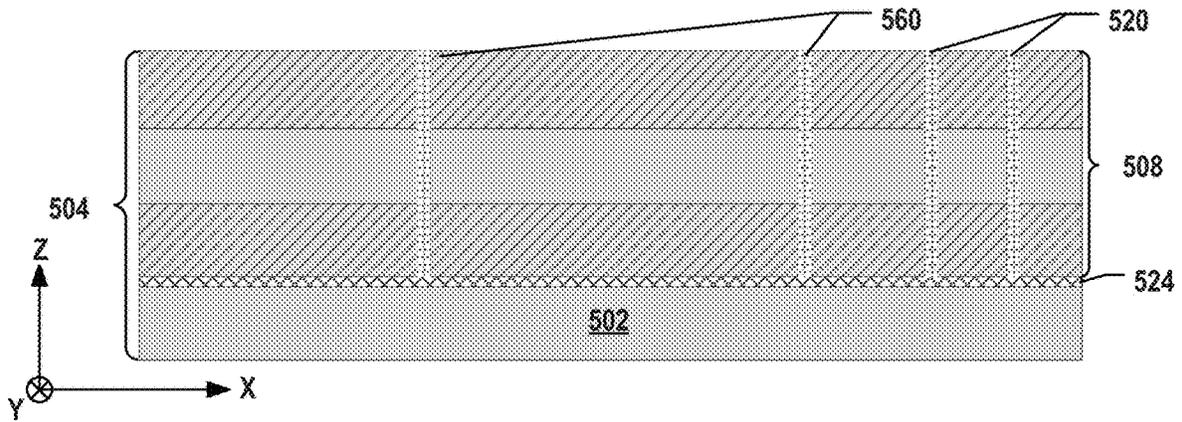


FIG. 5C

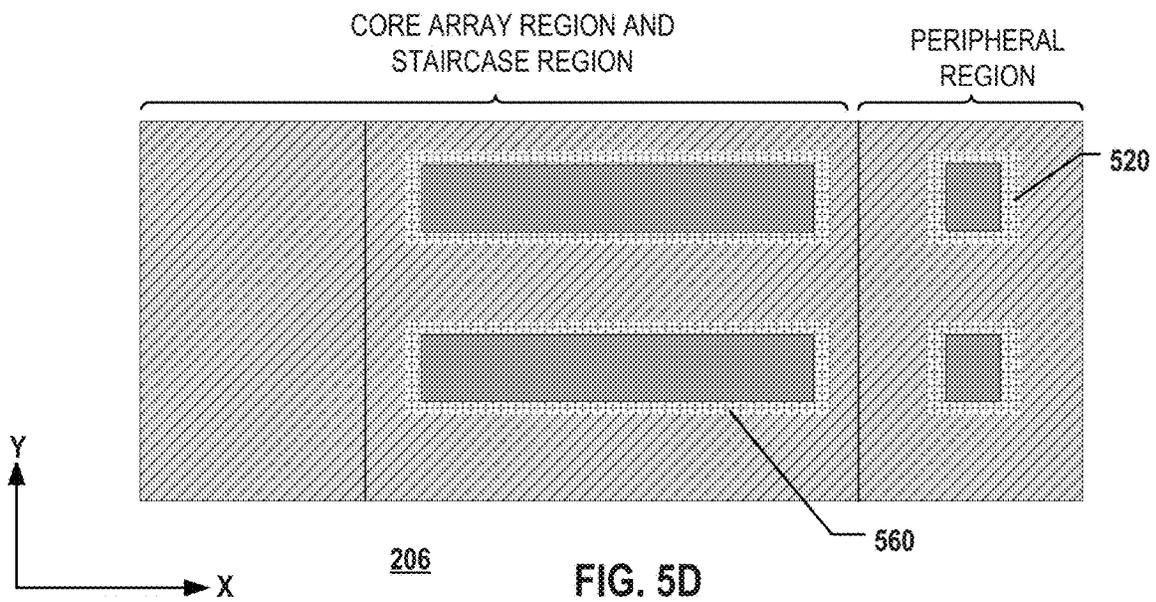


FIG. 5D

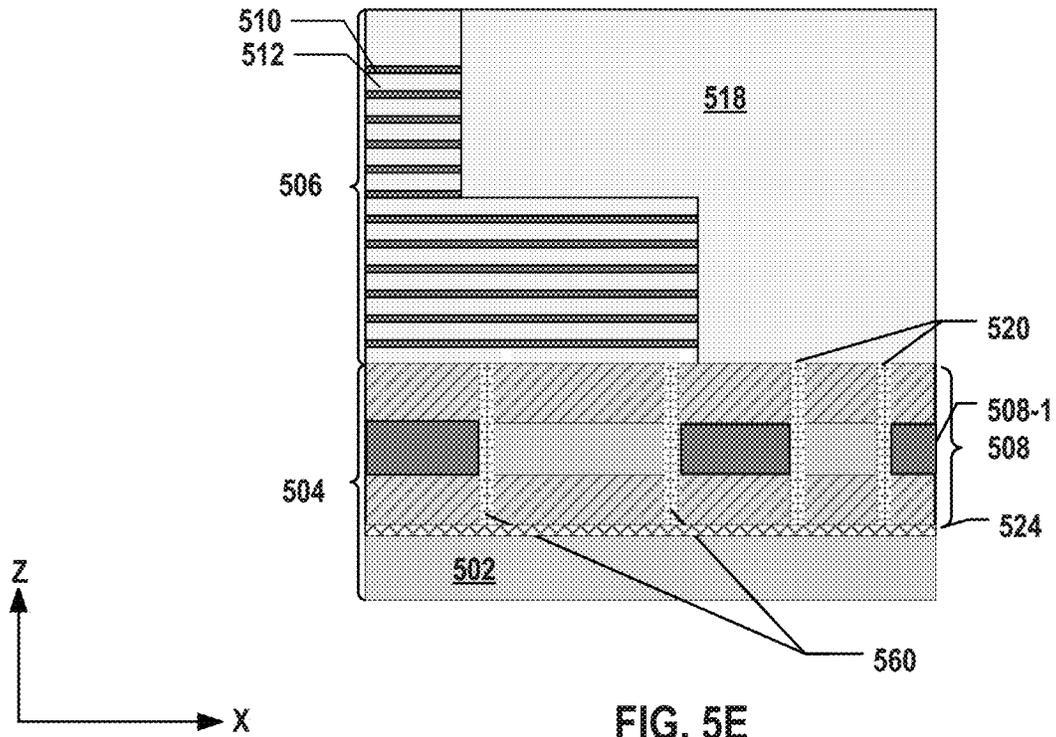


FIG. 5E

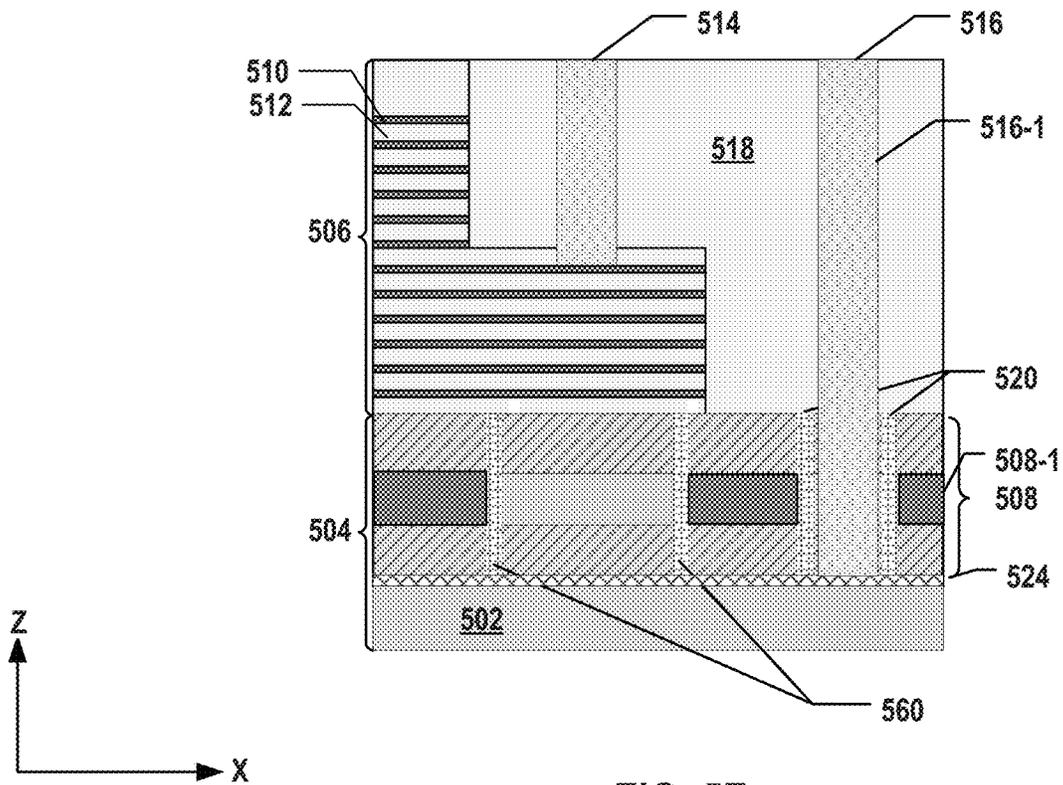


FIG. 5F

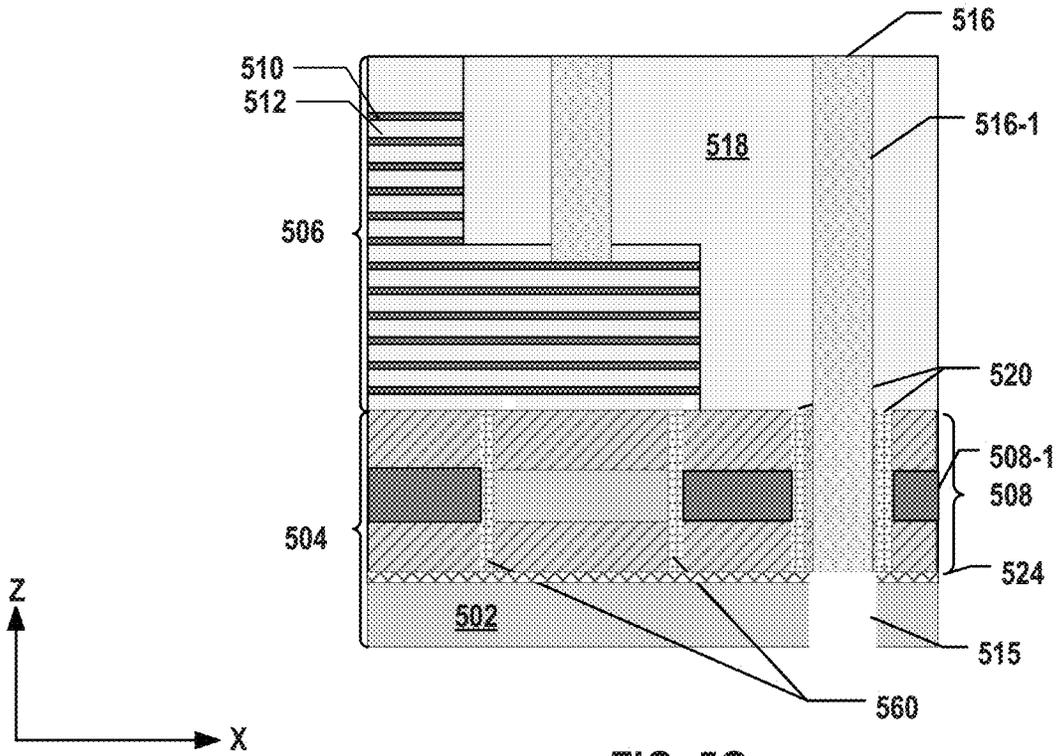


FIG. 5G

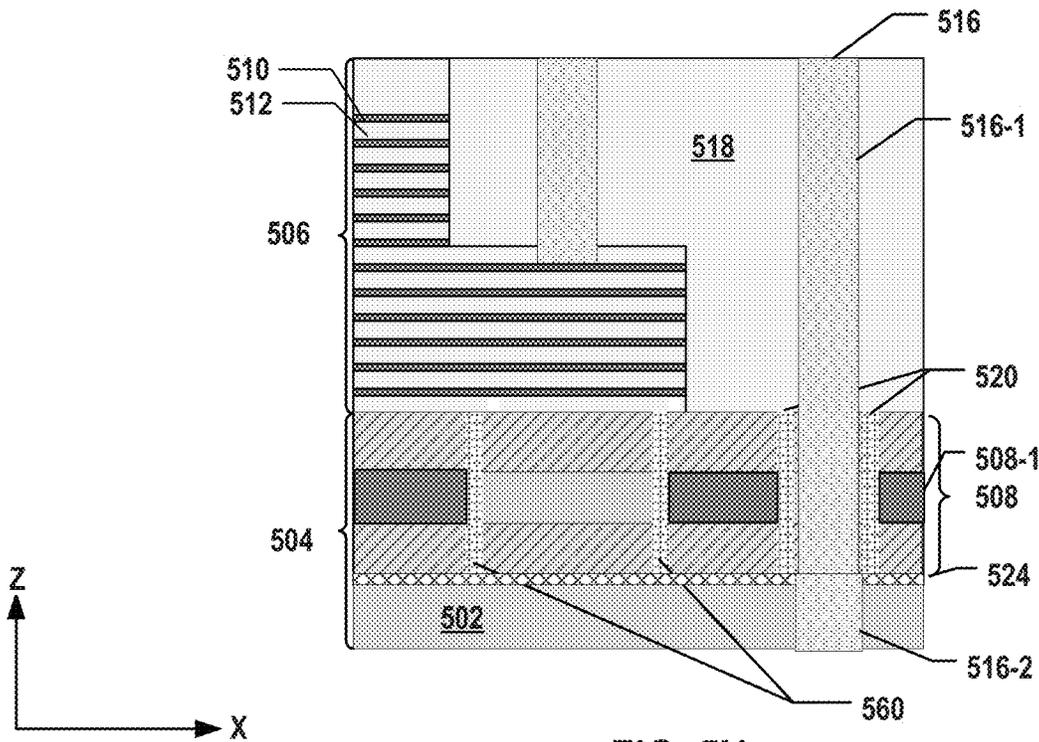


FIG. 5H

600

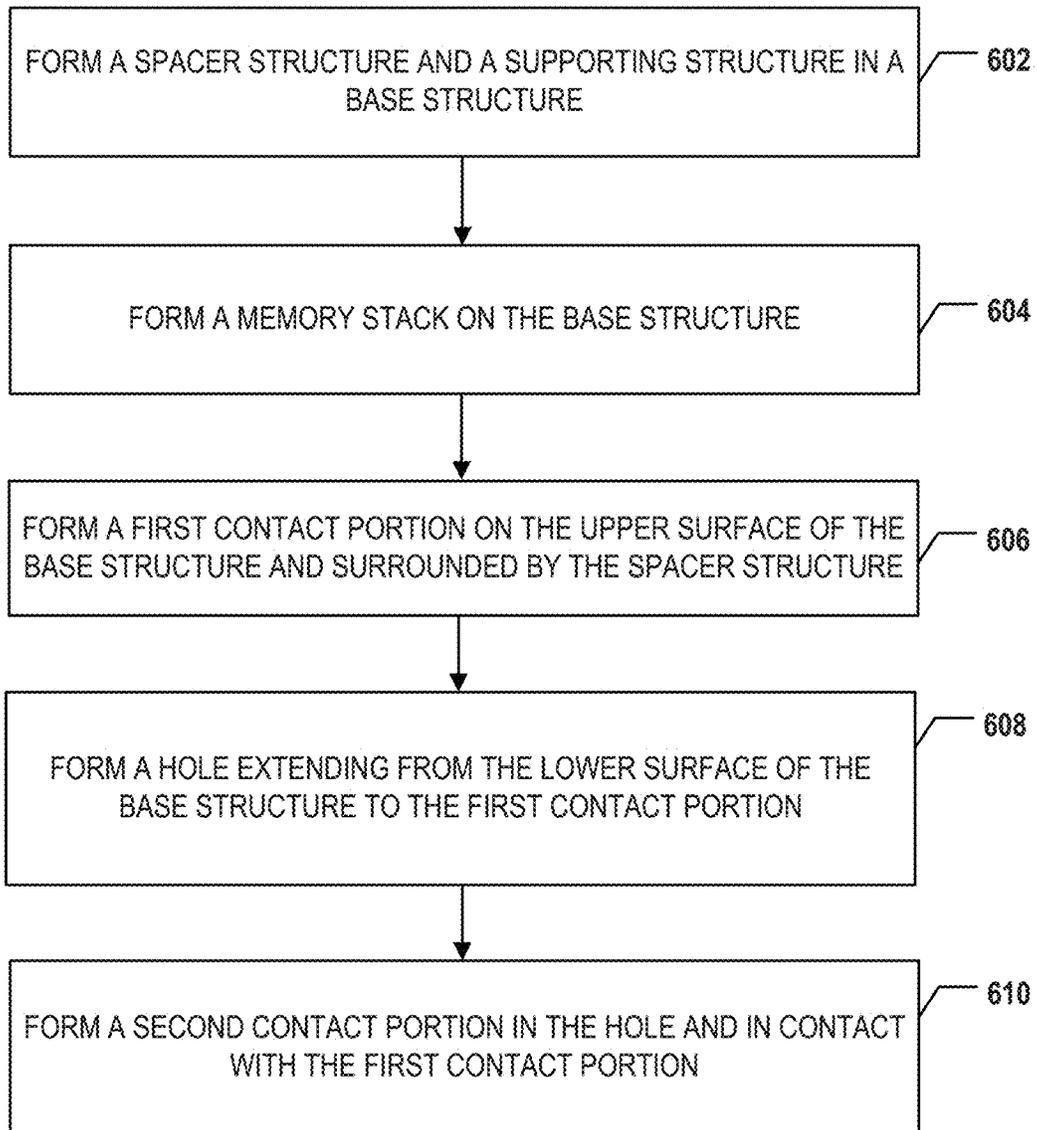


FIG. 6

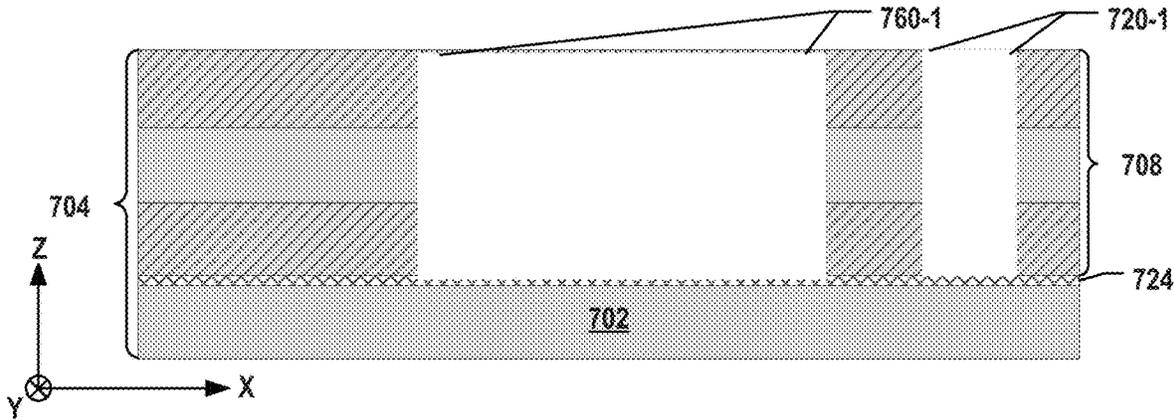


FIG. 7A

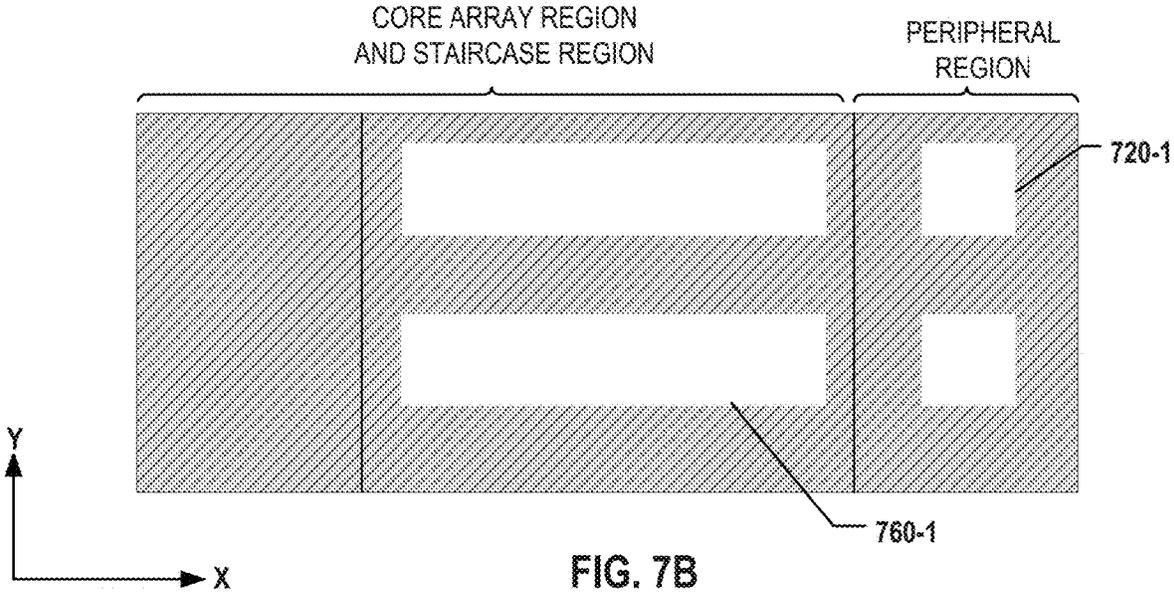


FIG. 7B

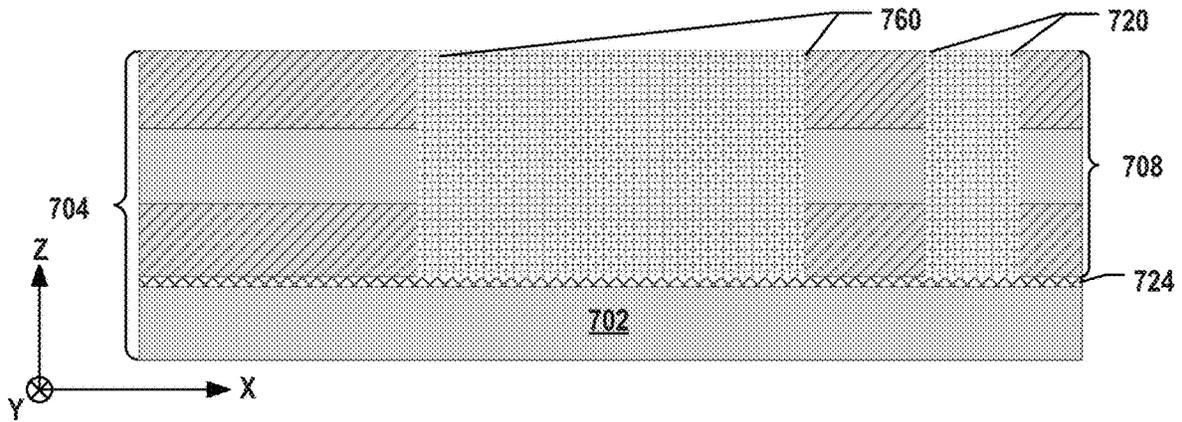


FIG. 7C

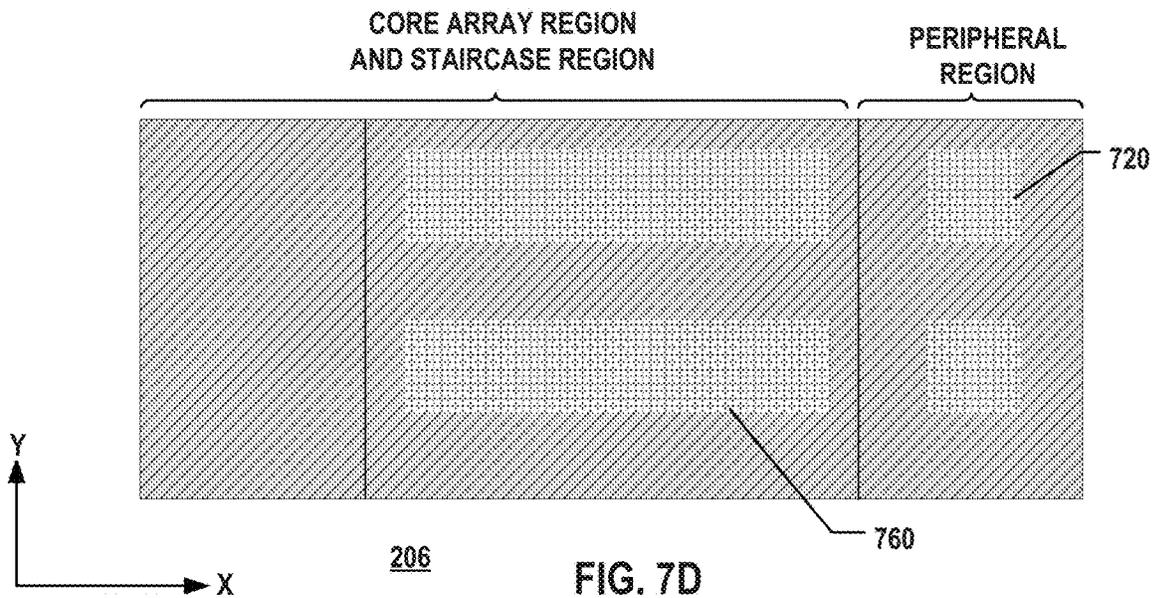


FIG. 7D

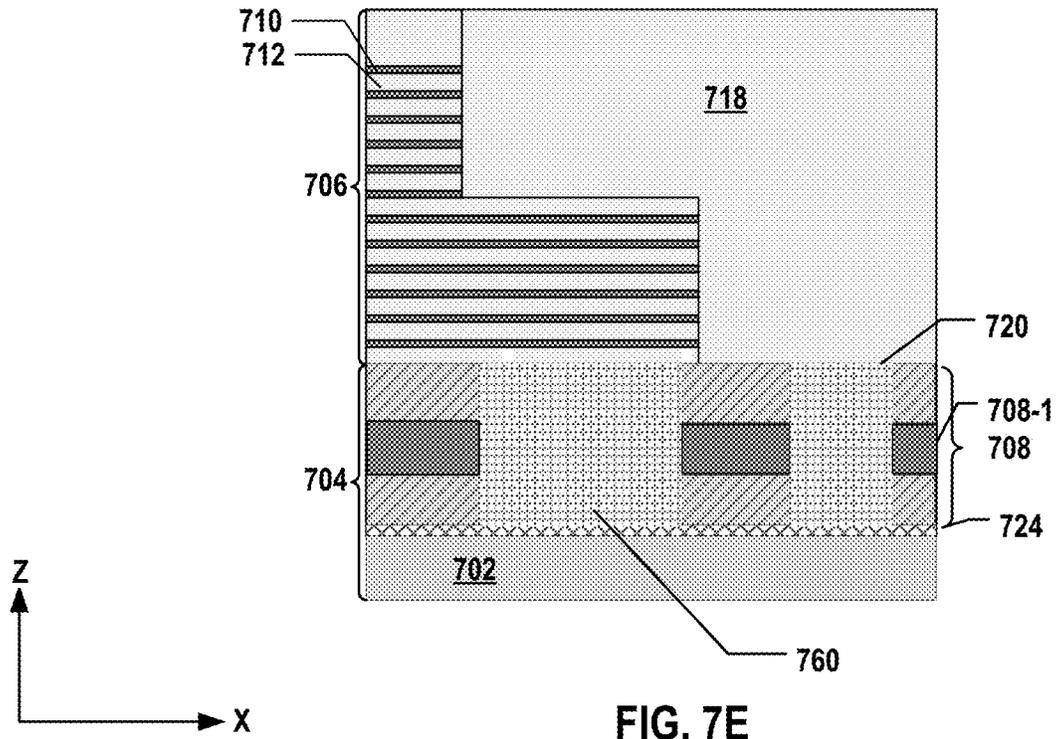


FIG. 7E

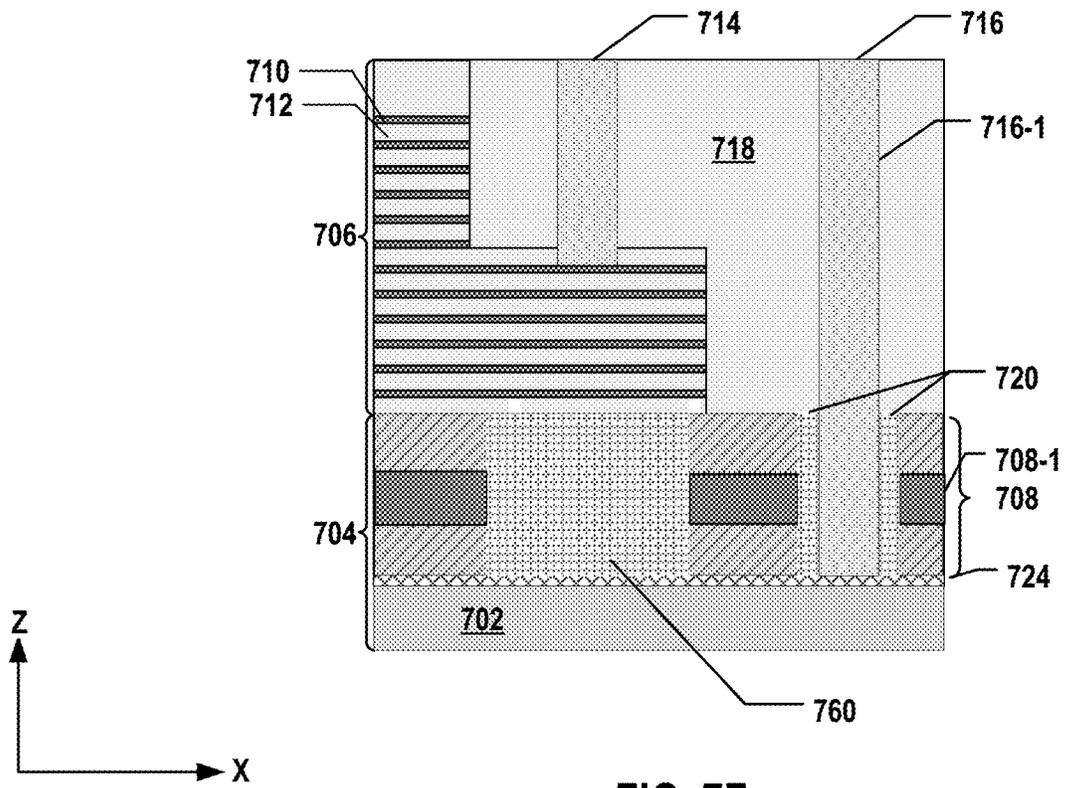


FIG. 7F

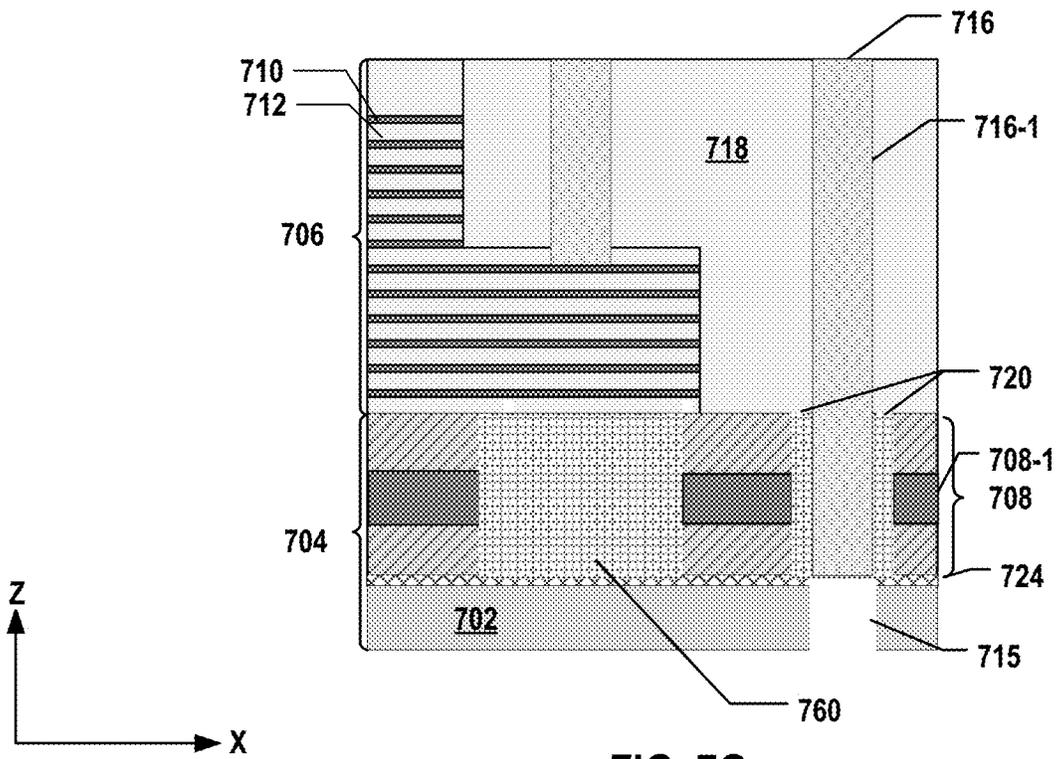


FIG. 7G

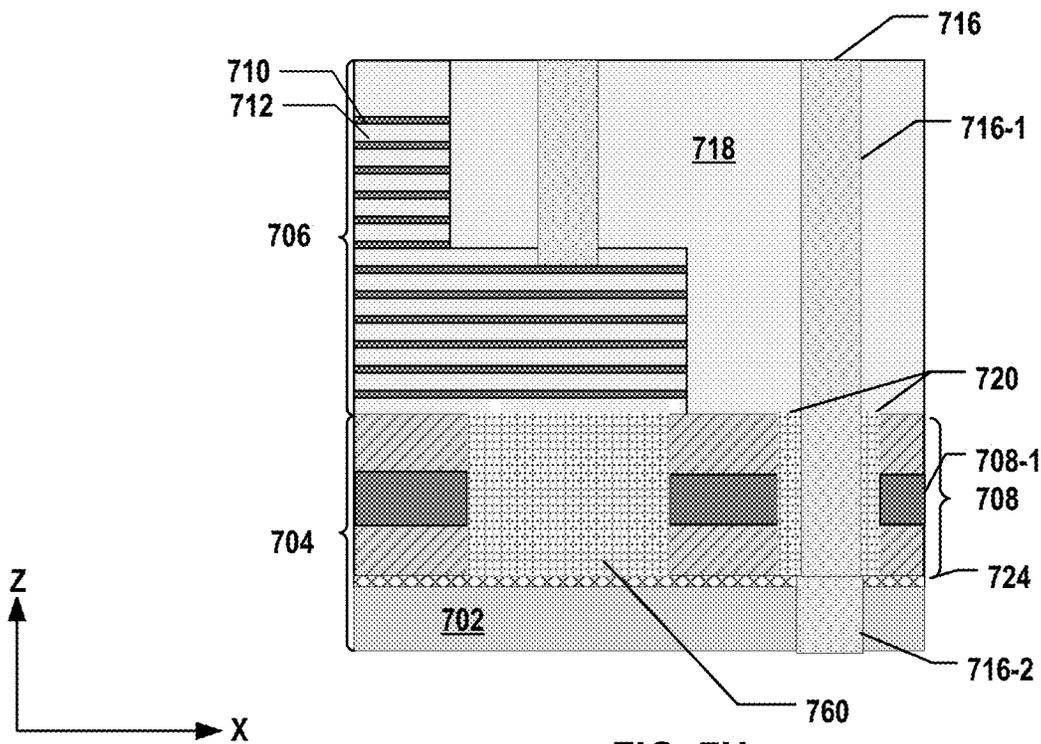


FIG. 7H

800

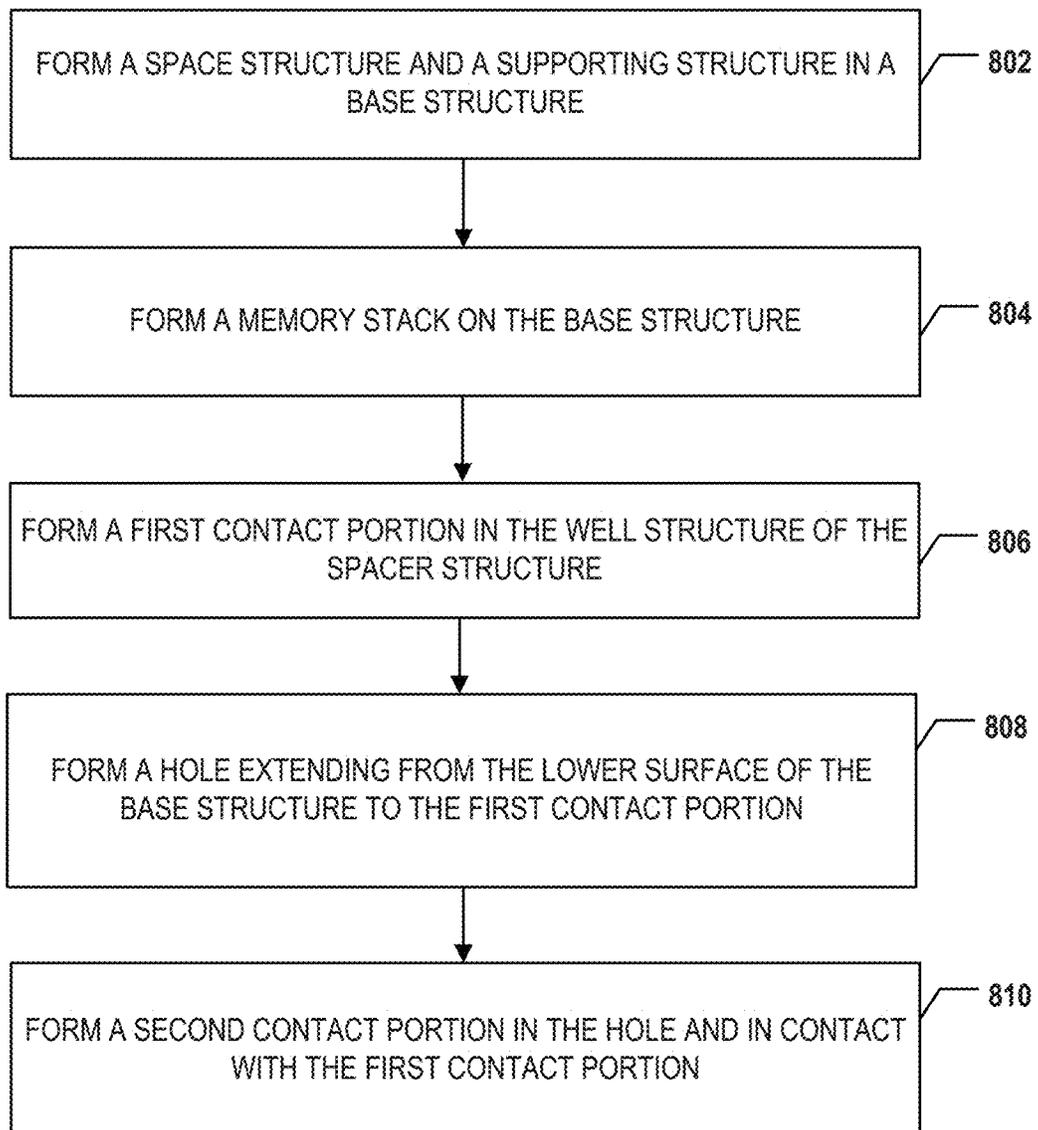


FIG. 8

**THREE-DIMENSIONAL MEMORY DEVICES
WITH SUPPORTING STRUCTURE FOR
STAIRCASE REGION AND SPACER
STRUCTURE FOR CONTACT STRUCTURE
AND METHODS FOR FORMING THE SAME**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is continuation of International Application No. PCT/CN2020/123597, filed on Oct. 26, 2020, entitled “THREE-DIMENSIONAL MEMORY DEVICES WITH SUPPORTING STRUCTURE FOR STAIRCASE REGION AND SPACER STRUCTURE FOR CONTACT STRUCTURE AND METHODS FOR FORMING THE SAME,” which is hereby incorporated by reference in its entirety.

BACKGROUND

Embodiments of the present disclosure relate to three-dimensional (3D) memory devices and fabrication methods thereof.

Planar memory cells are scaled to smaller sizes by improving process technology, circuit design, programming algorithm, and fabrication process. However, as feature sizes of the memory cells approach a lower limit, planar process and fabrication techniques become challenging and costly. As a result, memory density for planar memory cells approaches an upper limit.

A 3D memory architecture can address the density limitation in planar memory cells. The 3D memory architecture includes a memory array and peripheral devices for controlling signals to and from the memory array.

SUMMARY

Embodiments of 3D memory devices and methods for forming the same are disclosed herein.

In one example, a 3D memory device includes a memory stack, a semiconductor layer, a supporting structure, a spacer structure, and a contact structure. The memory stack includes interleaved conductive layers and dielectric layers and includes a staircase region in a plan view. The semiconductor layer is in contact with the memory stack. The supporting structure overlaps the staircase region of the memory stack and is coplanar with the semiconductor layer. The supporting structure includes a material other than a material of the semiconductor layer. The spacer structure is outside the memory stack and is coplanar with the supporting structure and the semiconductor layer. The contact structure extends vertically and is surrounded by the spacer structure.

In another example, a 3D memory device includes a memory stack, a semiconductor layer, a supporting structure, a spacer structure, a channel structure, and a contact structure. The memory stack includes interleaved conductive layers and dielectric layers and includes a staircase region in a plan view. The semiconductor layer is in contact with the memory stack. The supporting structure overlaps the staircase region of the memory stack and is coplanar with the semiconductor layer. The supporting structure includes a material other than a material of the semiconductor layer. The spacer structure is outside the memory stack and is coplanar with the supporting structure and the semiconductor layer. The channel structure is in the core array region of the memory stack and is into the semiconductor layer. The

channel structure includes a semiconductor channel, and a lower portion of the semiconductor channel is in contact with the semiconductor layer. The contact structure extends vertically and is surrounded by the spacer structure.

In still another example, a method for forming a 3D memory device is disclosed. A semiconductor layer including a sacrificial layer is formed on a substrate. A supporting structure and a spacer structure are simultaneously formed in the semiconductor layer. The supporting structure and the spacer structure are coplanar with the semiconductor layer. A dielectric stack including a staircase region is formed in contact with the semiconductor layer. The staircase region overlaps with the supporting structure. A contact structure extending vertically and surrounded by the spacer structure is formed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate embodiments of the present disclosure and, together with the description, further serve to explain the principles of the present disclosure and to enable a person skilled in the pertinent art to make and use the present disclosure.

FIGS. 1A-1C illustrate exemplary 3D memory devices with supporting structures for staircase regions and spacer structures for contact structures, according to various embodiments of the present disclosure.

FIGS. 2A-2C illustrate another exemplary 3D memory devices with supporting structures for staircase regions and spacer structures for contact structures, according to various embodiments of the present disclosure.

FIGS. 3A-3C illustrate another exemplary 3D memory devices with supporting structures for staircase regions and spacer structures for contact structures, according to various embodiments of the present disclosure.

FIG. 4 illustrates part of an exemplary 3D memory device, according to various embodiments of the present disclosure.

FIGS. 5A-5H illustrate an exemplary fabrication process for forming a 3D memory device, according to some embodiments of the present disclosure.

FIG. 6 illustrates a flowchart of a method for forming a 3D memory device, according to some embodiments of the present disclosure.

FIGS. 7A-7H illustrate an exemplary fabrication process for forming a 3D memory device, according to some embodiments of the present disclosure.

FIG. 8 illustrates a flowchart of a method for forming a 3D memory device, according to some embodiments of the present disclosure.

Embodiments of the present disclosure will be described with reference to the accompanying drawings.

DETAILED DESCRIPTION

Although specific configurations and arrangements are discussed, it should be understood that this is done for illustrative purposes only. A person skilled in the pertinent art will recognize that other configurations and arrangements can be used without departing from the spirit and scope of the present disclosure. It will be apparent to a person skilled in the pertinent art that the present disclosure can also be employed in a variety of other applications.

It is noted that references in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” “some embodiments,” etc., indicate that the embodi-

ment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases do not necessarily refer to the same embodiment. Further, when a particular feature, structure or characteristic is described in connection with an embodiment, it would be within the knowledge of a person skilled in the pertinent art to effect such feature, structure or characteristic in connection with other embodiments whether or not explicitly described.

In general, terminology may be understood at least in part from usage in context. For example, the term “one or more” as used herein, depending at least in part upon context, may be used to describe any feature, structure, or characteristic in a singular sense or may be used to describe combinations of features, structures or characteristics in a plural sense. Similarly, terms, such as “a,” “an,” or “the,” again, may be understood to convey a singular usage or to convey a plural usage, depending at least in part upon context. In addition, the term “based on” may be understood as not necessarily intended to convey an exclusive set of factors and may, instead, allow for existence of additional factors not necessarily expressly described, again, depending at least in part on context.

It should be readily understood that the meaning of “on,” “above,” and “over” in the present disclosure should be interpreted in the broadest manner such that “on” not only means “directly on” something but also includes the meaning of “on” something with an intermediate feature or a layer therebetween, and that “above” or “over” not only means the meaning of “above” or “over” something but can also include the meaning it is “above” or “over” something with no intermediate feature or layer therebetween (i.e., directly on something).

Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations), and the spatially relative descriptors used herein may likewise be interpreted accordingly.

As used herein, the term “substrate” refers to a material onto which subsequent material layers are added. The substrate itself can be patterned. Materials added on top of the substrate can be patterned or can remain unpatterned. Furthermore, the substrate can include a wide array of semiconductor materials, such as silicon, germanium, gallium arsenide, indium phosphide, etc. Alternatively, the substrate can be made from an electrically non-conductive material, such as a glass, a plastic, or a sapphire wafer.

As used herein, the term “layer” refers to a material portion including a region with a thickness. A layer can extend over the entirety of an underlying or overlying structure or may have an extent less than the extent of an underlying or overlying structure. Further, a layer can be a region of a homogeneous or inhomogeneous continuous structure that has a thickness less than the thickness of the continuous structure. For example, a layer can be located between any pair of horizontal planes between, or at, a top surface and a bottom surface of the continuous structure. A layer can extend horizontally, vertically, and/or along a tapered surface. A substrate can be a layer, can include one or more layers therein, and/or can have one or more layer

thereupon, thereabove, and/or therebelow. A layer can include multiple layers. For example, an interconnect layer can include one or more conductor and contact layers (in which interconnect lines and/or vertical interconnect access (via) contacts are formed) and one or more dielectric layers.

As used herein, the term “nominal/nominally” refers to a desired, or target, value of a characteristic or parameter for a component or a process operation, set during the design phase of a product or a process, together with a range of values above and/or below the desired value. The range of values can be due to slight variations in manufacturing processes or tolerances. As used herein, the term “about” indicates the value of a given quantity that can vary based on a particular technology node associated with the subject semiconductor device. Based on the particular technology node, the term “about” can indicate a value of a given quantity that varies within, for example, 10-30% of the value (e.g., $\pm 10\%$, $\pm 20\%$, or $\pm 30\%$ of the value).

As used herein, the term “3D memory device” refers to a semiconductor device with vertically oriented strings of memory cell transistors (referred to herein as “memory strings,” such as NAND memory strings) on a laterally-oriented substrate so that the memory strings extend in the vertical direction with respect to the substrate. As used herein, the term “vertical/vertically” means nominally perpendicular to the lateral surface of a substrate.

In some 3D NAND memory devices, semiconductor plugs are selectively grown to surround the sidewalls of channel structures, e.g., known as sidewall selective epitaxial growth (SEG). Compared with another type of semiconductor plugs that are formed at the lower ends of the channel structures, e.g., bottom SEGs, the formation of sidewall SEGs avoids the etching of the memory film and semiconductor channel at the bottom surface of channel holes (also known as “SONO” punch), thereby increasing the process window, in particular when fabricating 3D NAND memory devices with advanced technologies, such as having 96 or more levels with a multi-deck architecture.

Sidewall SEGs are usually formed by replacing a sacrificial layer between the substrate and a memory stack with the sidewall SEGs, which involves multiple deposition and etching processes through the slit openings. However, since the sacrificial layer is a continuous layer extending across both the core array region and the staircase region of the memory stack, in fabricating the sidewall SEGs, the removal of the sacrificial layer and parts of the memory films (e.g., having silicon oxide and silicon nitride) to expose the semiconductor channels can result in lack of support for the memory stack in the staircase region, causing the memory stack to collapse.

Moreover, the sidewall SEGs can be combined with backside processes to form source contact structures from the backside of the substrate to, e.g., avoid leakage current and parasitic capacitance between front side source contact structures and word lines, increasing the effective device area. Peripheral contacts, such as through-silicon contacts (TSCs), formed in the peripheral region and facilitating electrical contact between memory cells and peripheral circuits, can also be formed using backside processes in these 3D NAND memory devices. However, the fabrication of peripheral contacts faces challenges because of increasing levels of the 3D NAND memory devices. Short circuits, caused by the electrical contact between the highly doped polysilicon between the bottom of the peripheral contact, may occur.

Various embodiments in accordance with the present disclosure provide 3D memory devices with supporting

structures for staircase regions, and spacer structures for peripheral contacts. In the present disclosure, part of a semiconductor layer (e.g., a polysilicon layer), having a sacrificial layer, is replaced with a supporting structure overlapping with the staircase region. As used herein, one component (e.g., a layer or a structure) is “overlapping” another component (e.g., a layer or a structure) of a 3D memory device refers to the component being aligned with the other component in a vertical direction (e.g., one component is either “below” or “above” the other component). When removing the sacrificial layer to form the sidewall SEGs, the supporting structure in the staircase region can provide support to the memory stack, thereby avoiding the collapse and increasing yield. Also, by replacing part of the semiconductor layer with a spacer structure outside the memory stack (e.g., in the peripheral region), the spacer structure can surround the peripheral contacts and insulate the peripheral contacts from the semiconductor layer, thereby avoiding short circuits.

The supporting structures can have various designs as long as at least part of the supporting structure in contact with the semiconductor layer includes a material other than the material of the sacrificial layer to stop the etching into the staircase region when removing the sacrificial layer. The spacer structures can also have various designs as long as at least part of the spacer structure surrounding the peripheral contact includes a dielectric material that can insulate the peripheral contact from the semiconductor layer.

In some embodiments, to increase yield, the supporting structure and the spacer structure may include the same kind of dielectric material such as silicon oxide and/or tetraethyl orthosilicate (TEOS) and may be formed simultaneously. For example, the supporting structure and the spacer structure can be formed by the same etch process followed by the same deposition process. The etch and the deposition processes can be performed separately or incorporated into the current process flow without additional fabrication steps. For example, the etch process can be performed in any suitable etching/patterning process for forming another structure in the semiconductor device prior to the formation of the contact structure, and the deposition process can be any suitable deposition process for forming another structure in the semiconductor device prior to the formation of the contact structure. In some embodiments, the etch process is performed using a zero mask, which is employed for patterning structures in the substrate prior to the formation of any structures on a base structure (e.g., a semiconductor layer including the sacrificial layer). In some embodiments, the etch process is the same patterning process that patterns structures (e.g., bottom-select-gate cut structures in a memory stack) on the base structure. In some embodiments, the deposition process can be the same deposition process that forms the insulating structure in which a memory stack is located. The fabrication process can thus be simplified.

FIG. 1A illustrates a side view of a cross-section of an exemplary 3D memory device **100** with a supporting structure for a staircase region and spacer structure for contact structure, according to some embodiments of the present disclosure. FIG. 1B illustrates a section view along line A-A' of 3D memory device **100** shown in FIG. 1A, according to some embodiments. FIG. 1C illustrates a section view along line B-B' of 3D memory device **100** shown in FIG. 1B, according to some embodiments. For the ease of illustration, FIGS. 1A, 1B, and 1C are described together.

As shown in FIG. 1A, 3D memory device **100** includes a base structure **104**, an insulating structure **118** over base structure **104**, and a contact structure **116** extending in

insulating structure **118** and base structure **104**. 3D memory device **100** may also include a substrate on which base structure **104** is located on. In some embodiments, 3D memory device **100** includes a memory stack **106** over base structure **104** and in insulating structure **118**. 3D memory device **100** may include a word line contact **114**, in insulating structure **118**, in contact with and conductively connected to memory stack **106**. In some embodiments, 3D memory device **100** includes a source contact structure **126** (shown in FIG. 4 and will be described in detail below) in contact with and conductively connected to base structure **104**. In some embodiments, contact structure **116** is located in a peripheral region of 3D memory device **100**. Memory stack **106** may be located in a core array region and/or a staircase region of 3D memory device **100**. As an example, in the present disclosure, the 3D memory devices are represented by 3D NAND memory devices, and contact structures, e.g., **116**, are described as peripheral contacts in the 3D NAND memory devices. In some embodiments, contact structure **116** electrically connects a peripheral circuit and a contact pad (not shown) on opposite sides of base structure **104** of 3D memory device **100**, such that the peripheral circuit can be electrically connected to external circuits through the contact pad. In some embodiments, contact structure **116** is electrically connected to a peripheral circuit and source contact structure **126** on opposite sides of base structure **104** of 3D memory device **100**, such that the peripheral circuit can be electrically connected to source contact structure **126** to control the operations of the source of the 3D NAND memory device. It should be understood that the structures and fabrication methods to form these contact structures can be employed to form contact structures in any other suitable structures/devices as well.

The substrate of 3D memory device **100** can include silicon (e.g., single crystalline silicon), silicon germanium (SiGe), gallium arsenide (GaAs), germanium (Ge), silicon on insulator (SOI), germanium on insulator (GOI), or any other suitable materials. In some embodiments, the substrate is a thinned substrate (e.g., a semiconductor layer), which was thinned by grinding, etching, chemical mechanical polishing (CMP), or any combination thereof. In some embodiments, the substrate is removed and not included in 3D memory device **100**. It is noted that x, y, and z axes are included in figures of the present disclosure to further illustrate the spatial relationship of the components in semiconductor devices. As an example, the substrate of 3D memory device **100** includes two lateral surfaces (e.g., an upper surface and a lower surface) extending laterally in the x-direction and the y-direction (i.e., the lateral directions). The z-direction represents the direction perpendicular to the x-y plane (i.e., the plane formed by the x-direction and y-direction). As used herein, whether one component (e.g., a layer or a device) is “on,” “above,” or “below” another component (e.g., a layer or a device) of a 3D memory device (e.g., 3D memory device **100**) is determined relative to the substrate of the semiconductor device in the z-direction (i.e., the vertical direction) when the substrate is positioned in the lowest plane of the semiconductor device in the z-direction. The same notion for describing the spatial relationships is applied throughout the present disclosure.

In some embodiments, 3D memory device **100** is part of a non-monolithic 3D NAND memory device, in which the components are formed separately on different substrates and then bonded in a face-to-face manner, a face-to-back manner, or a back-to-back manner. Peripheral devices (not shown), such as any suitable digital, analog, and/or mixed-signal peripheral circuits used for facilitating the operation

of 3D memory device **100**, can be formed on a separate peripheral device substrate different from the memory array substrate on which the components shown in FIG. 1A are formed. It is understood that the memory array substrate may be removed from 3D memory device **100**, and the peripheral device substrate may become the substrate of 3D memory device **100**. It is further understood that depending on the way how the peripheral device substrate and the memory array device substrate are bonded, the memory array devices (e.g., shown in FIG. 1A) may be in the original positions or may be flipped upside down in 3D memory device **100**. For ease of reference, FIG. 1A depicts a state of 3D memory device **100** in which the memory array devices are in the original positions (i.e., not flipped upside down). However, it is understood that, in some examples, the memory array devices shown in FIG. 1A may be flipped upside down in 3D memory device **100**, and their relative positions may be changed accordingly. The same notion for describing the spatial relationships is applied throughout the present disclosure.

As shown in FIG. 1A, base structure **104** can include an insulating layer **102** and a semiconductor layer **108** (e.g., a polysilicon layer) on insulating layer **102**. Optionally, base structure **104** may include a stop layer **124** between insulating layer **102** and semiconductor layer **108**. Insulating layer **102** can include one or more interlayer dielectric (ILD) layers (also known as “intermetal dielectric (IMD) layers”) in which the interconnect lines and VIA contacts can form. The ILD layers of insulating layer **102** can include dielectric materials including, but not limited to, silicon oxide, silicon nitride, silicon oxynitride, low dielectric constant (low-k) dielectrics, or any combination thereof. In some embodiments, insulating layer **102** includes silicon oxide. Stop layer **124**, if any, can be disposed directly on insulating layer **102**. Stop layer **124** can be a single-layered structure or a multiple-layered structure. In some embodiments, stop layer **124** is a single-layered structure and includes a high dielectric constant (high-k) dielectric layer. In some embodiments, stop layer **124** is a double-layered structure and includes a first stop layer on a second stop layer. The first stop layer can include silicon nitride, and the second stop layer can include high-k dielectric. The high-k dielectric layer can include, for example, aluminum oxide, hafnium oxide, zirconium oxide, or titanium oxide, to name a few. In one example, stop layer **124** may include aluminum oxide. As described below in detail, since the function of stop layer **124** is to stop the etching of channel holes, supporting structure openings, and spacer structure openings, it is understood that stop layer **124** may include any other suitable materials that have a relatively high etching selectivity (e.g., greater than about 5) with respect to the materials in the layers thereabove. In some embodiments, besides functioning as an etch stop layer, stop layer **124** also functions as the backside substrate thinning stop layer.

Semiconductor layer **108** may be disposed directly on stop layer **124**. In some embodiments, a pad oxide layer (e.g., a silicon oxide layer) is disposed between stop layer **124** and semiconductor layer **108** to relax the stress between semiconductor layer **108** and stop layer **124** (e.g., an aluminum oxide layer). Semiconductor layer **108** includes an N-type doped polysilicon layer, according to some embodiments. That is, semiconductor layer **108** can be doped with any suitable N-type dopants, such as phosphorus (P), arsenic (As), or antimony (Sb), which contribute free electrons and increase the conductivity of the intrinsic semiconductor. Semiconductor layer **108** may include a semiconductor sublayer **108-1** (e.g., a polysilicon sublayer) between the top

and lower surfaces of semiconductor layer **108**. For example, semiconductor sublayer **108-1** may be formed by replacing at least part of a sacrificial sublayer of an initial semiconductor layer (e.g., having a sacrificial sublayer between the top and lower surfaces and later forms semiconductor layer **108**), and may be conductively connected to the semiconductor channel of a 3D NAND memory string and the source contact structure of 3D memory device **100**. As described below in detail, due to a diffusion process, semiconductor layer **108** can have a suitable uniform doping concentration profile in the vertical direction. It is understood that as semiconductor sublayer **108-1** of semiconductor layer **108** may have the same polysilicon material as the rest of semiconductor layer **108**, and the doping concentration may be uniform in semiconductor layer **108** after diffusion, semiconductor sublayer **108-1** may not be distinguishable from the rest of semiconductor layer **108** in 3D memory device **100**. Nevertheless, semiconductor sublayer **108-1** refers to the part of semiconductor layer **108** that is in contact with the semiconductor channel, instead of the memory film, in the lower portion of the channel structure.

Although FIG. 1A shows that semiconductor layer **108** is above stop layer **124** as described above, it is understood that stop layer **124** may be above semiconductor layer **108** in some examples because the memory array devices shown in FIG. 1A may be flipped upside down, and their relative positions may be changed accordingly in 3D memory device **100**. Although in the present disclosure semiconductor layer **108** is described as the conductive layer for facilitating electrical coupling between the source contact of 3D memory device **100** and memory stack **106**, in various embodiments, any other suitable conductive material may also be formed between memory stack **106** and insulating layer **102** for performing similar/same functions as semiconductor layer **108**.

Memory stack **106** can include a plurality of interleaved conductor layers **110** and dielectric layers **112** over semiconductor layer **108**. Conductor layers **110** and dielectric layers **112** in memory stack **106** can alternate in the vertical direction. In other words, except for the ones at the top or bottom of memory stack **106**, each conductor layer **110** can be adjoined by two dielectric layers **112** on both sides, and each dielectric layer **112** can be adjoined by two conductor layers **110** on both sides. Conductor layers **110** can include conductive materials including, but not limited to, tungsten (W), cobalt (Co), copper (Cu), aluminum (Al), polysilicon, doped silicon, silicides, or any combination thereof. Each conductor layer **110** can include a gate electrode (gate line) surrounded by an adhesion layer and a gate dielectric layer. The gate electrode of conductor layer **110** can extend laterally as a word line, ending at one or more staircase structures of memory stack **106**. Dielectric layers **112** can include dielectric materials including, but not limited to, silicon oxide, silicon nitride, silicon oxynitride, or any combination thereof. Memory stack **106** may have a staircase structure, which includes a plurality of stairs, e.g., extending laterally along the x/y direction. Each stair may include one or more pairs of conductor layer **110** and dielectric layers **112** (referred to as conductor/dielectric layer pairs). Word line contact **114**, extending in insulating structure **118**, may be in contact with and conductively connected to a top conductor layer **110** of a respective stair, as shown in FIG. 1A. Word line contact **114** can include conductive materials including, but not limited to, W, Co, Cu, Al, polysilicon, doped silicon, silicides, or any combination thereof. Insulating structure **118** can include dielectric

materials including, but not limited to, silicon oxide, silicon nitride, silicon oxynitride, or any combination thereof.

In some embodiments, 3D memory device **100** is a 3D NAND memory device and includes a plurality of memory cells formed in the core array region of memory stack **106**. The memory cells may be formed by the intersections of 3D NAND memory strings (e.g., channel structures) in memory stack **106** and conductor layers **110**. FIG. **4** illustrates a cross-sectional view of a channel structure in memory stack **106**.

As shown in FIG. **4**, a channel structure **412** extends vertically through the core array region of memory stack **106** and semiconductor layer **108**, stopping at stop layer **124**, if any. That is, channel structure **412** can include two portions: the lower portion surrounded by semiconductor layer **108** (i.e., below the interface between semiconductor layer **108** and memory stack **106**) and the upper portion surrounded by memory stack **106** (i.e., above the interface between semiconductor layer **108** and memory stack **106**). As used herein, the “upper portion/end” of a component (e.g., channel structure **412**) is the portion/end farther away from the substrate in the z-direction, and the “lower portion/end” of the component (e.g., channel structure **412**) is the portion/end closer to the substrate in the z-direction when the substrate is positioned in the lowest plane of 3D memory device **100**. In some embodiments, each channel structure **412** does not extend further beyond stop layer **124** as the etching of the channel hole being stopped by stop layer **124**. For example, the lower end of channel structure **412** may be nominally flush with the upper surface of stop layer **124**.

Channel structure **412** can include a channel hole filled with semiconductor material(s) (e.g., as a semiconductor channel **416**) and dielectric material(s) (e.g., as a memory film **414**). In some embodiments, semiconductor channel **416** includes silicon, such as amorphous silicon, polysilicon, or single crystalline silicon. In one example, semiconductor channel **416** includes polysilicon. In some embodiments, memory film **414** is a composite layer including a tunneling layer, a storage layer (also known as a “charge trap layer”), and a blocking layer. The remaining space of the channel hole can be partially or fully filled with a capping layer **418** including dielectric materials, such as silicon oxide, and/or an air gap. Channel structure **412** can have a cylinder shape (e.g., a pillar shape). Capping layer **418**, semiconductor channel **416**, the tunneling layer, the storage layer, and the blocking layer of memory film **414** are arranged radially from the center toward the outer surface of the pillar in this order, according to some embodiments. The tunneling layer can include silicon oxide, silicon oxynitride, or any combination thereof. The storage layer can include silicon nitride, silicon oxynitride, or any combination thereof. The blocking layer can include silicon oxide, silicon oxynitride, high-k dielectrics, or any combination thereof. In one example, memory film **414** can include a composite layer of silicon oxide/silicon oxynitride/silicon oxide (ONO). In some embodiments, channel structure **412** further includes a channel plug **420** at the top of the upper portion of channel structure **412**. Channel plug **420** can include semiconductor materials (e.g., polysilicon). In some embodiments, channel plug **420** functions as the drain of the NAND memory string.

As shown in FIG. **4**, part of semiconductor channel **416** along the sidewall of channel structure **412** (e.g., in the lower portion of channel structure **412**) is in contact with semiconductor sublayer **108-1**, according to some embodiments. That is, memory film **414** is disconnected in the lower portion of channel structure **412** that abuts semiconductor sublayer **108-1** of semiconductor layer **108**, exposing semi-

conductor channel **416** to be in contact with the surrounding semiconductor sublayer **108-1**, according to some embodiments. As a result, semiconductor sublayer **108-1** surrounding and in contact with semiconductor channel **416** can work as the “sidewall SEG” of channel structure **412**. In some embodiments, a source contact structure **126** is in contact with semiconductor layer **108** and is electrically connected to semiconductor channel **416** through semiconductor layer **108**.

As shown in FIG. **4**, in some embodiments, 3D memory device **100** further includes an insulating spacer **422** extending vertically through interleaved conductor layers **110** and dielectric layers **112** of memory stack **106**. In some embodiments, insulating spacer **422** extends into semiconductor layer **108** and stops at semiconductor sublayer **108-1**, according to some embodiments. In some embodiments, the lower end of insulating spacer **422** is nominally flush with the upper surface of semiconductor sublayer **108-1**. Each insulating spacer **422** can also extend laterally to separate channel structures **412** into a plurality of blocks. Different from the slit structures in some 3D NAND memory devices, insulating spacer **422** does not include any contact therein (i.e., not functioning as the source contact), according to some embodiments. In some embodiments, each insulating spacer **422** includes an opening (e.g., a slit) filled with one or more dielectric materials, including, but not limited to, silicon oxide, silicon nitride, silicon oxynitride, or any combination thereof. In one example, each insulating spacer **422** may be filled with silicon oxide as an insulator core **426** and high-k dielectrics connecting with the gate dielectric layers.

Source contact structure **126** may extend vertically through insulating layer **102** and stop layer **124** (if any) from the opposite side of semiconductor layer **108** with respect to stop layer **124** (i.e., the backside) to be in contact with semiconductor layer **108**. It is understood that the depth that source contact structure **126** extends into semiconductor layer **108** may vary in different examples. Source contact structure **126** can electrically connect the source of the channel structure of 3D memory device **100** to the peripheral devices through semiconductor layer **108** from the backside of the memory array substrate (removed) and thus, can be referred to herein as a “backside source pick up” as well. Source contact structure **126** can include any suitable types of contacts. In some embodiments, source contact structure **126** includes a VIA contact. In some embodiments, source contact structure **126** includes a wall-shaped contact extending laterally. Source contact structure **126** can include one or more conductive layers, such as a metal layer, for example, tungsten (W), cobalt (Co), copper (Cu), or aluminum (Al) or a silicide layer surrounded by an adhesive layer (e.g., titanium nitride (TiN)).

Referring back to FIG. **1A**, contact structure **116** may extend in insulating structure **118** and base structure **104** and may be conductively connected to any peripheral circuits for the operation of memory cells. In some embodiments, contact structure **116** extends through semiconductor layer **108** and insulating layer **102**. Contact structure **116** may include a first contact portion **116-1** extending in insulating structure **118** and semiconductor layer **108**, and a second contact portion **116-2** extending in insulating layer **102**, and stop layer **124** if any. First and second contact portions **116-1** and **116-2** may be in contact with and conductively connected to each other at a contact interface. 3D memory device **100** may also include a spacer structure **120** in

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semiconductor layer **108** surrounding first contact portion **116-1** such that first contact portion **116-1** is insulated from semiconductor layer **108**.

In some embodiments, a lateral cross-sectional area of second contact portion **116-2** is greater than or equal to a lateral cross-sectional area of first contact portion **116-1** such that first contact portion **116-1** is fully overlapped with second contact portion **116-2**. The lateral cross-sections of first and second contact portions **116-1** and **116-2** can each have any suitable shapes such as oval, squared, rectangular, and circular shapes. For example, the lateral cross-section of first and second contact portions **116-1** and **116-2** may respectively be nominally circular and squared. The upper surface of second contact portion **116-2** may be sufficiently flat, e.g., nominally leveled/coplanar with the upper surface of insulating layer **102** (or stop layer **124** if any). The contact interface between first and second contact portions **116-1** and **116-2** may be coplanar (or at least nominally coplanar) with the upper surface of insulating layer **102** (or stop layer **124** if any). That is, the lower surface of first contact portion **116-1** and the upper surface of second contact portion **116-2** may each be coplanar (or at least nominally coplanar with) with the upper surface of insulating layer **102** (or stop layer **124** if any). In some embodiments, first and second contact portions **116-1** and **116-2** can each be made of tungsten, cobalt, copper, or aluminum, and/or silicide.

Spacer structure **120** may be in semiconductor layer **108**, surrounding/enclosing first contact portion **116-1** such that first contact portion **116-1** (or contact structure **116**) is insulated from semiconductor layer **108**. For example, compared with some known 3D memory devices, part of the initial semiconductor layer (e.g., the semiconductor layer with the sacrificial sublayer between the top and lower surfaces) may be replaced with spacer structure **120** so that spacer structure **120** encloses and insulates first contact portion **116-1** of contact structure **116** from the part of the initial semiconductor layer outside spacer structure **120**, before semiconductor layer **108** is formed. That is, the portion of sacrificial sublayer of the initial semiconductor layer enclosed by spacer structure **120** may not be replaced with a portion of sublayer **108-1** of semiconductor layer **108**. In some embodiments, as illustrated in FIG. 1B, spacer structure **120** may have a trench structure (e.g., a ring structure) enclosing/surrounding first contact portion **116-1** (or contact structure **116**) laterally. It is understood that the trench structure of spacer structure **120** may have any suitable shapes such as oval, squared, rectangular, and circular shapes in the plan view as long as the lateral dimensions of spacer structure **120** (e.g., in the x-y plane) are sufficiently large to insulate first contact portion **116-1** from semiconductor layer **108** in all directions.

For example, the trench structure of spacer structure **120** may be in a rectangular shape and divides semiconductor layer **108** into an insulating portion **108I** (e.g., part of the initial semiconductor layer, the sacrificial sublayer of which is not replaced) and a sacrificial portion **108S**. An upper surface of spacer structure **120**, in contact with insulating structure **118**, may be coplanar with the upper surface of semiconductor layer **108**. A lower surface of spacer structure **120** may be in contact with insulating layer **102** (or stop layer **124** if any) such that insulating portion **108I** is fully insulated from the rest part of semiconductor layer **108** (e.g., sacrificial portion **108S**) by the trench structure. Accordingly, because first contact portion **116-1** is surrounded by and in contact with insulating portion **108I**, even though first contact portion **116-1** may be electrically connected to insulating portion **108I**, both first contact portion **116-1** and

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insulating portion **108I** are fully insulated from the rest part of semiconductor layer **108** by the trench structure. Therefore, no additional spacer layer in contact structure **116** is needed to prevent short circuits at the bottom of first contact portion **116-1**, reducing the complexity of fabricating contact structure **116** and increasing yield.

In various embodiments, the lower surface of spacer structure **120** can be leveled with or below the lower surface of semiconductor layer **108**. For example, the lower surface of spacer structure **120** may be in stop layer **124** or in insulating layer **102**. In some embodiments, spacer structure **120** includes a dielectric material, such as silicon oxide, silicon nitride, silicon oxynitride, TEOS, or a combination thereof. It should be understood that, if spacer structure **120** includes the same material as insulating structure **118** and/or insulating layer **102**, the upper surface and/or lower surface of spacer structure **120** may not be distinguishable.

Referring back to FIG. 1A, 3D memory device **100** further includes a supporting structure **160** in semiconductor layer **108**, below memory stack **106**. Semiconductor layer **108** and supporting structure **160** are coplanar, i.e., in the same plane below memory stack **106**, according to some embodiments. For example, compared with some known 3D memory devices, part of the initial semiconductor layer (e.g., the semiconductor layer with a sacrificial sublayer between the top and lower surfaces) may be replaced with supporting structure **160** for the staircase region of memory stack **106** before semiconductor layer **108** is formed (e.g., by replacing at least part of the sacrificial sublayer of the initial semiconductor layer). In some embodiments, supporting structure **160** at least partially overlaps with the staircase region of memory stack **106**. That is, along the x-y plane, the area enclosed by supporting structure **160** can overlap at least part of the staircase region to provide support for the staircase region when replacing the sacrificial sublayer in the initial semiconductor layer. Semiconductor layer **108** can fill in the space outside supporting structure **160**, e.g., between memory stack **106** and insulating layer **102** (or stop layer **124**, if any). In some embodiments, semiconductor layer **108** is disposed in at least part of the core array region in which channel structures (e.g., channel structures **412** in FIG. 4) are formed. In some embodiments, semiconductor layer **108** is part of the staircase region. As shown in FIGS. 1A and 1B, supporting structure **160** is aligned with staircase region in the vertical direction (e.g., perpendicular to the x-y plane).

In some embodiments, part of supporting structure **160** in contact with semiconductor layer **108** includes a material other than, e.g., different from the material of semiconductor layer **108**. For example, the part of supporting structure **160** may include silicon oxide and/or TEOS, different from polysilicon in semiconductor layer **108**. As shown in FIG. 1B, in some embodiments, supporting structure **160** includes a trench structure (e.g., a ring structure) in contact with semiconductor layer **108** to prevent part of the initial semiconductor layer (e.g., the part of the sacrificial sublayer enclosed by supporting structure **160**) from being replaced when semiconductor layer **108** is formed. As a result, when replacing the sacrificial sublayer, the enclosed/protected part of the sacrificial sublayer will be retained, providing support for the memory stack **106** in the staircase region so that the memory stack **106** is less susceptible to collapse.

It is understood that the trench structure of supporting structure **160** may have any suitable shapes such as oval, squared, rectangular, and circular shapes in the plan view as long as at least part of supporting structure **160** overlaps and is aligned with the staircase region of memory stack **106** and least part of supporting structure **160** in contact with the

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semiconductor layer includes a material other than the material of the sacrificial layer to stop the etching into the staircase region when replacing the sacrificial sublayer.

For example, as shown in FIGS. 1B and 1C, the trench structure of supporting structure 160 may be in a rectangular shape such that semiconductor layer 108 may be divided into a supporting portion 108P (e.g., part of the initial semiconductor layer, the sacrificial layer of which is not replaced) and sacrificial portion 108S. An upper surface of supporting structure 160, in contact with memory stack 106, may be coplanar with the upper surface of semiconductor layer 108. A lower surface of supporting structure 160 may be in contact with insulating layer 102 (or stop layer 124 if any) such that supporting portion 108P is fully protected by the trench structure from being etched when semiconductor layer 108 is formed (e.g., by performing the sacrificial sublayer replacement to the initial semiconductor layer). Accordingly, supporting portion 108P will provide support for the staircase region of memory stack 106 to avoid collapse when the sacrificial sublayer is replaced.

In some embodiments, for ease of production, both spacer structure 120 and supporting structure 160 may have the same kind of dielectric material, such as silicon oxide, or TEOS, to name a few. As will be described in detail below, spacer structure 120 and supporting structure 160 may also be fabricated in the same etching and deposition process. For example, the etch process may be performed using a zero mask, which is employed for patterning spacer structure 120 and supporting structure 160 in the initial semiconductor layer before the sacrificial sublayer is replaced for forming semiconductor layer 108.

As shown in the plan view of FIG. 1B, 3D memory device 100 includes a plurality of memory blocks 103 (for ease of illustration, only one memory block 103 is shown) separated by slit structures 130 (e.g., first slit structures). It is noted that x and y axes are included in FIG. 1B to illustrate two orthogonal directions in the substrate plane. The x-direction is the word line direction, and the y-direction is the bit line direction. Adjacent memory blocks 103 arranged in the y-direction (e.g., the bit line direction) are separated by a respective slit structure 130 extending laterally in the x-direction (e.g., the word line direction). In each memory block 103, slit structures 130-1 having "H" cuts 105 (e.g., second slit structures) further separate memory block 103 into multiple memory fingers 107, each of which includes an array of channel structures (e.g., channel structures 412 shown in FIG. 4) in the core array region. That is, slit structure 130 between memory blocks 103 is a continuous structure through the memory plane, which cuts off memory stack 106 between adjacent memory blocks 103, whereas slit structure 130-1 between memory fingers 107 within memory block 103 includes one or more "H" cuts 105 that connect memory stack 106 between adjacent memory fingers 107. As illustrated in FIG. 1C, slit structure 130-1 with "H" cuts 105 extends laterally through the entire memory stack 106 and stops in semiconductor layer 108. As illustrated in FIGS. 1B and 1C, supporting structure 160 is divided by slit structure 130-1 with "H" cuts 105 into multiple sub-supporting structures 160-1, each sub-supporting structure 160-1 corresponds to (e.g., overlaps and/or aligned with) one memory finger 106, and thus, can provide support to corresponding fingers during sacrificial sublayer replacement.

FIG. 2A illustrates a side view of a cross-section of another exemplary 3D memory device 200 with a supporting structure for a staircase region and spacer structures for contact structures, according to some embodiments. FIG. 2B

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illustrates a section view along line A-A' of 3D memory device 200 shown in FIG. 2A, according to some embodiments. FIG. 2C illustrates a section view along line B-B' of 3D memory device 200 shown in FIG. 2B, according to some embodiments. For the ease of illustration, FIGS. 2A, 2B, and 2C are described together, and the details of the same structures in both 3D memory devices 100 and 200 are not repeated for ease of description.

As shown in FIG. 2A, 3D memory device 200 includes a contact structure 216, a spacer structure 220, and a supporting structure 260. Contact structure 216 may include a first contact portion 216-1 and a second contact portion 216-2 in contact with and conductively connected to each other. Contact structure 216 may extend through spacer structure 220 such that spacer structure 220 insulates contact structure 216 from semiconductor layer 108. Different from spacer structure 120, instead of having a trench structure dividing semiconductor layer 108 into different parts, spacer structure 220 may have a well structure 220-1 filled with a dielectric material (e.g., taking up the entire space that is enclosed by spacer structure 220). For example, first contact portion 216-1 (or contact structure 216) may extend through and in contact with spacer structure 220 (e.g., in contact with the dielectric material of spacer structure 220) such that first contact portion 216-1 is insulated from semiconductor layer 108 by well structure 220-1 of spacer structure 220. It is understood that well structure 220-1 of spacer structure 220 may have any suitable shape such as oval, squared, rectangular, and circular shapes in the plan view as long as the lateral dimensions of spacer structure 220 (e.g., in the x-y plane) is sufficiently large to insulate first contact portion 216-1 from semiconductor layer 108 in all directions. It is also understood that the shape of well structure 220-1 can be the same or different from the shape of the contact structure. The other properties of first and second contact portions 216-1 and 216-2, and spacer structure 220, such as the material, the position of the upper and lower surface, etc., may respectively be similar to or the same as those for first and second contact portions 116-1 and 116-2 and spacer structure 120, and the detailed description is not repeated herein.

Moreover, different from supporting structure 160, instead of having a trench structure dividing semiconductor layer 108 into different parts, supporting structure 260 may also have a well structure 260-2 filled with a material different than the material of semiconductor layer 108 (e.g., taking up the entire space that supporting structure 260 encloses). For example, supporting structure 260 may include a well structure 260-2 (e.g., filled with a dielectric material) taking up the entire space enclosed by supporting structure 260. It is understood that well structure 260-2 of supporting structure 260 may have any suitable shape such as oval, squared, rectangular, and circular shapes in the plan view so long as at least part of well structure 260-2 overlaps and is aligned with the staircase region of memory stack 106 and at least part of supporting structure 260 in contact with the semiconductor layer includes a material other than the material of the sacrificial sublayer to stop the etching into the staircase region when replacing the sacrificial sublayer. Similar to supporting structure 160, supporting structure 260 may also be divided into multiple sub-supporting structures 260-1 by slit structures 130-1 with "H" cuts 105. The material and the position of the upper and lower surface of supporting structure 260 may respectively be similar to or the same as those for supporting structure 160, and the detailed description is not repeated herein.

Although in 3D memory device **100**, both spacer structure **120** and supporting structure **160** have a trench structure, and in 3D memory device **200**, both spacer structure **220** and supporting structure **260** have a well structure, it is understood that the embodiments of the trench structure and the well structure are interchangeable. That is, in some embodiments, 3D memory device **100** may have a spacer structure with a trench structure and a supporting structure with a well structure. In some other embodiments, 3D memory device **200** may have a spacer structure with a well structure and a supporting structure with a trench structure.

FIG. **3A** illustrates a side view of a cross-section of another exemplary 3D memory device **300** with a supporting structure for a staircase region and spacer structures for the contact structures, according to some embodiments. FIG. **3B** illustrates a section view along line A-A' of 3D memory device **300** shown in FIG. **3B**, according to some embodiments. FIG. **3C** illustrates a section view along line B-B' of 3D memory device **300** shown in FIG. **3B**, according to some embodiments. For the ease of illustration, FIGS. **3A**, **3B**, and **3C** are described together, and the details of the same structures in both 3D memory devices **100**, **200**, and **300** are not repeated for ease of description.

3D memory devices **300** have a supporting structure **360** overlaps and aligned with the staircase region of memory stack **106**. As shown in FIG. **3C**, 3D memory devices **300** have slit structures **330-1** with "H" cuts **105** (e.g., second slit structures) extending into supporting structure **360**.

Different from supporting structures **160** and **260**, instead of having multiple sub-supporting structures **160-1** and **260-1** divided by slit structures **130-1** with "H" cuts **105**, supporting structures **360** within each memory block **103** may not be divided by slit structures **330-1** with "H" cuts **105** and may extend continuously along the y-direction. In other words, as illustrated in FIG. **3C**, one memory block **103** corresponds to (e.g., overlaps and/or aligned with) one continuous supporting structure **360**. Different from 3D memory devices **100** and **200**, instead of extending into semiconductor layer **108**, slit structures **330-1** with "H" cuts **105** extend into supporting structure **360**. The material and the position of the upper and lower surface of supporting structure **360** may respectively be similar to or the same as those for supporting structure **360**, and the detailed description is not repeated herein.

Although as shown in FIGS. **3A**, **3B**, and **3C**, in 3D memory device **300**, spacer structure **220** includes a well structure, it is understood that spacer structure **220** can have other suitable embodiments such as a trench structure, similar to or the same as spacer structure **120** as illustrated in FIGS. **1A**, **1B**, and **1C**.

FIGS. **5A-5H** illustrate a fabrication process for forming a 3D memory device, according to some embodiments of the present disclosure. FIG. **6** illustrates a flowchart of a method **600** for forming a 3D memory device, according to some embodiments of the present disclosure. Examples of the 3D memory device depicted in FIGS. **5A-5H** and **6** include the 3D memory device depicted in FIGS. **1A-1C** and **3A-3C**. FIGS. **5A-5H** and **6** will be described together. It is understood that the operations shown in method **600** are not exhaustive and that other operations can be performed as well before, after, or between any of the illustrated operations. Further, some of the operations may be performed simultaneously, or in a different order than shown in FIG. **6**.

Referring to FIG. **6**, method **600** starts at operations **602**, in which a supporting structure opening and a spacer structure opening are simultaneously formed in a base structure, and a supporting structure and a spacer structure are formed

in the supporting structure opening and the spacer structure opening respectively. FIGS. **5A-5D** illustrate corresponding structures.

As shown in FIGS. **5A** and **5B**, at the beginning of the fabrication process, a supporting structure opening, and a spacer structure opening are simultaneously formed in a base structure **504**. In some embodiments, the supporting structure opening and the spacer structure opening are formed by the same fabrication steps/operations. The shapes and depth of the trench structure may correspond to those of the subsequently-formed supporting structure and spacer structure. Base structure **504** may include an initial semiconductor layer **508** on a stop layer **524**, which is further on an insulating layer **502**. Initial semiconductor layer **508** may include a sacrificial sublayer, which can partially be replaced by a semiconductor sublayer **508-1** for forming semiconductor layer **508**. The detailed description of initial semiconductor layer **508**, semiconductor layer **508**, stop layer **524**, and insulating layer **502** may be referred to the description of the initial semiconductor layer, semiconductor layer **108**, stop layer **124**, and insulating layer **102**, and is not repeated herein.

Base structure **504** may be formed on one side (e.g., the first side) of a substrate. The substrate can be a silicon substrate or a carrier substrate, made of any suitable materials, such as semiconductors, glass, sapphire, plastic, to name a few. In some embodiments, insulating layer **502** includes a dielectric material such as silicon oxide. In some embodiments, stop layer **524** includes a high-k dielectric material such as aluminum oxide. In some embodiments, later formed semiconductor layer **508** includes polysilicon having a uniform doping profile. In some embodiments, insulating layer **502**, stop layer **524**, and initial semiconductor layer **508** are sequentially formed on the substrate by any suitable film deposition methods such as chemical vapor deposition (CVD), physical vapor deposition (PVD), atomic layer deposition (ALD), electroplating, electroless deposition, and a combination thereof. Subsequently, the substrate may be removed or thinned for forming various structures such as contact vias. In some embodiments, the substrate is removed or thinned at a suitable time of the fabrication process such that contact vias can be formed from the lower surface of base structure **504**.

The spacer structure opening may have a trench structure **520-1** enclosing an area in the peripheral region of base structure **504** (e.g., initial semiconductor layer **508**) such that the enclosed area (e.g., in initial semiconductor layer **508**) may be insulated from the portion of initial semiconductor layer **508** outside of trench structure **520-1**. In some embodiments, trench structure **520-1** may extend from the upper surface of initial semiconductor layer **508** to at least the lower surface of initial semiconductor layer **508**. For example, the lower surface of trench structure **520-1** may stop on or in stop layer **524**. In some embodiments, the lower surface of initial semiconductor layer **508** stops at stop layer **524**. A thickness/depth of trench structure **520-1** may at least be the thickness of initial semiconductor layer **508** along the z-direction. Trench structure **520-1** may be formed by any suitable patterning process such as dry etch and/or wet etch, following a photolithography process.

The supporting structure opening may have a trench structure **560-1** enclosing part of initial semiconductor layer **508** in the staircase region of base structure **504** (e.g., initial semiconductor layer **508**) such that the sacrificial sublayer of the enclosed area (e.g., the part of initial semiconductor layer **508**) may be protected from being replaced when semiconductor layer **508** is formed. In some embodiments,

trench structure **560-1** may extend from the upper surface of initial semiconductor layer **508** to at least the lower surface of initial semiconductor layer **508**. For example, the lower surface of trench structure **560-1** may stop on or in stop layer **524**. In some embodiments, the lower surface of initial semiconductor layer **508** stops at stop layer **524**. A thickness/depth of trench structure **560-1** may at least be the thickness of along the z-direction. Trench structure **560-1** of supporting structure **560** may be formed by the same patterning process as that of trench structure **520-1** of spacer structure **520**. For example, the spacer structure opening and the supporting structure opening can be formed, in the peripheral region and the staircase region of the 3D memory device respectively and simultaneously, e.g., using the same etching process, by patterning base structure **504** (e.g., initial semiconductor layer **508**) using a “zero mask,” which is used for patterning base structure **504** before any structure is formed thereon.

As shown in FIGS. **5C** and **5D**, a spacer structure **520** may be formed in the spacer structure opening. A dielectric material, e.g., silicon oxide and/or TEOS, can be deposited to fill trench structure **520-1** of the spacer structure opening, forming spacer structure **520**. The dielectric material may be deposited by any suitable film deposition method such as CVD, PVD, ALD, and a combination thereof.

A supporting structure **560** (shown in FIGS. **5C** and **5D**) may be formed in the supporting structure opening. A material different from the material of initial semiconductor layer **508**, e.g., a dielectric material such as silicon oxide and/or TEOS, can be deposited to fill trench structure **560-1** of the supporting structure opening, forming supporting structure **560**. The filled material may be deposited by any suitable film deposition method such as CVD, PVD, ALD, and a combination thereof. In various embodiments, spacer structure **520** and supporting structures **560** can be formed by the same deposition process or separate deposition processes.

In some embodiments, to increase yield, the spacer structure opening and the supporting structure opening can both be filled with the same material in the same deposition process. For example, as illustrated in FIGS. **5C** and **5D**, the spacer structure opening and the supporting structure opening can both be filled with a dielectric material such as TEOS before a dielectric stack is formed on base structure **504**.

Referring back to FIG. **6**, method **600** proceeds to operation **604**, in which a memory stack including a core array region and a staircase region is formed on the base structure.

As illustrated in FIG. **5E**, a dielectric stack, which subsequently forms the memory stack, can be formed on base structure **504** on the substrate. The dielectric stack can include a plurality of interleaved sacrificial layers and dielectric layers. In some embodiments, the dielectric stack, having a plurality pairs of a sacrificial layer and a dielectric layer, is formed on semiconductor layer **508** and supporting structure **560**, the staircase region of which overlaps and is aligned with supporting structure **560**. The interleaved sacrificial layers and dielectric layers can be alternatively deposited on semiconductor layer **508** and supporting structure **560** to form the dielectric stack. In some embodiments, each dielectric layer includes a layer of silicon oxide, and each sacrificial layer includes a layer of silicon nitride. In some embodiments, a pad oxide layer (e.g., silicon oxide layer, not shown) is formed between semiconductor layer **508** and/or supporting structure **560**, and the dielectric stack. An insulating structure **518**, having a suitable dielectric material such as silicon oxide, can be deposited over the dielectric stack and base structure **504** at a suitable time

during the fabrication process, for example, after a staircase structure is formed (will be described below), such that the dielectric stack is located in insulating structure **518**. The dielectric stack, insulating structure **518**, and the pad oxide layer (if any) can be formed by one or more thin film deposition processes including, but not limited to, CVD, PVD, ALD, or any combination thereof.

Before the formation of the contact structure, other structures, although not shown in FIGS. **5A-5H**, can be formed in the 3D memory device (e.g., the dielectric stack). In some embodiments, a channel structure extending vertically through the dielectric stack, semiconductor layer **508**, and stopping at stop layer **524** is formed in the core array region of the dielectric stack. In some embodiments, to form the channel structure, a channel hole, e.g., an opening, extending vertically through the dielectric stack, and semiconductor layer **508**, is formed, and a memory film (e.g., a blocking layer, a storage layer, and a tunneling layer) and a semiconductor channel are sequentially formed along a sidewall of the channel hole. The deposition of the films and layers in the channel hole may include ALD, CVD, PVD, any other suitable processes, or any combination thereof. In some embodiments, a channel plug is formed above and in contact with the semiconductor channel. In some embodiments, fabrication processes for forming the channel hole include wet etching and/or dry etching processes, such as deep-ion reactive etching (DRIE). The etching of the channel hole continues until being stopped by stop layer **524**, due to the etching selectivity between the materials of stop layer **524** and semiconductor layer **508**, according to some embodiments.

To conductively connect semiconductor layer **508** and the channel structure, a semiconductor sublayer **508-1**, in contact with and conductively connected to the semiconductor channel, is formed in semiconductor layer **508**. In some embodiments, a lower portion of the memory film is removed such that the memory film becomes disconnected. Semiconductor sublayer **508-1**, in contact with the semiconductor channel, can be formed by replacing the sacrificial sublayer of initial semiconductor layer **508**, not enclosed by supporting structure **560** nor by spacer structure **520**. That is, the portions of sacrificial sublayer enclosed by supporting structure **560** and spacer structure **520** would stay intact during the replacement. The formation of semiconductor sublayer **508-1** may include suitable dry etch and/or wet etch processes, CVD, PVD, ALD, and a combination thereof. An insulating spacer, dividing the memory cells into a plurality of blocks, can also be formed. The formation of the insulating spacer may include suitable dry etch and/or wet etch processes, CVD, PVD, ALD, and a combination thereof.

In some embodiments, a slit structure is formed extending vertically through the dielectric stack, stopping in semiconductor layer **508** (e.g., in 3D memory device **100**). For example, a slit opening extends vertically through the dielectric stack, into initial semiconductor layer **508**, and exposes part of the sacrificial sublayer of initial semiconductor layer **508** may be formed. In some embodiments, fabrication processes for forming the slit opening include wet etching and/or dry etching, such as DRIE. In some embodiments, the slit opening extends further into the top portion of the sacrificial sublayer. The etching process through the dielectric stack may not stop at the top surface of the sacrificial sublayer and may continue to etch part of the sacrificial sublayer. The slit openings are formed between memory blocks **103**, as shown in FIG. **1B** (e.g., for forming first slit structures) and between memory fingers **107** (e.g., for forming second slit structures) according to

some embodiments. In some embodiments, the slit structure can be formed by depositing dielectrics into the slit opening using one or more thin film deposition processes, such as ALD, CVD, PVD, any other suitable processes, or any combination thereof. It is understood that although not shown, in some examples, the slit structure may be formed by depositing dielectrics (as a spacer) and conductive materials (as a contact) into the slit opening. As described above along with FIGS. 1B and 1C, the second slit structures (e.g., the slit structures between memory fingers 107) divide supporting structure 560 into multiple sub-supporting structures, each corresponding (e.g., overlaps and/or aligned with) to a memory finger divided by the second slit structures.

A gate replacement process can be performed to replace the sacrificial layers in the dielectric stack to form a plurality of conductor layers. In some embodiments, the gate replacement process is performed after the slit structures are formed and through the slit structures. A memory stack 506, having a plurality of interleaved conductor layers 510 and dielectric layers 512, can be formed on semiconductor layer 508. The gate replacement process may include a suitable isotropic etching process, CVD, PVD, ALD, and a combination thereof. The channel structures, extending through memory stack 506, may be in contact with and conductively connected to semiconductor layer 508 through the semiconductor channel. In some embodiments, memory stack 506 may be repetitively patterned to form a staircase structure in the staircase region, which includes a plurality of stairs extending laterally (e.g., along the x/y-direction). The patterning process of memory stack 506 may include repetitive photolithography processes and recess etches (e.g., an isotropic etching process).

Referring back to FIG. 6, method 600 proceeds to operation 606, in which a first contact portion is formed on the upper surface of the base structure and is surrounded by the trench structure of the spacer structure. FIG. 5F illustrates a corresponding structure.

As shown in FIG. 5F, a first contact portion 516-1 may be formed in spacer structure 520. First contact portion 516-1 may be formed in insulating structure 518 and landed on the lower surface of spacer structure 520. First contact portion 516-1 may be surrounded by spacer structure 520 and in contact with the part of semiconductor layer 508 enclosed by spacer structure 520. That said, the lateral dimensions of first contact portion 516-1 may be less than the lateral dimensions of the area enclosed by spacer structure 520 (or the filled trench structure 520-1). First contact portion 516-1 is therefore isolated from semiconductor layer 508 outside of spacer structure 520. In some embodiments, first contact portion 516-1 is formed by the same process that forms a word line contact 514, which lands on a respective stair to form a conductive connection with conductor layer 510 in the stair. First contact portion 516-1 and word line contact 514 may each include a suitable conductive material such as tungsten. In some embodiments, the lower surface of first contact portion 516-1 does not reach the lower surface of spacer structure 520 but is below the upper surface of semiconductor layer 508 such that the etching from the lower surface of base structure 504 can be reduced when the second contact portion is being formed. That is, the hole to form the second contact portion does not need to reach the upper surface of semiconductor layer 508 from the lower surface of base structure 504, i.e., insulating layer 502.

The formation of first contact portion 516-1 and word line contact 514 may include a patterning process followed by a suitable film deposition process. The patterning process may

remove portions of insulating structure 518 to form openings, at desired depths, that correspond to the locations and positions of first contact portion 516-1 and word line contact 514. In some embodiments, the opening for first contact portion 516-1 extends in insulating structure 518 and exposes the enclosed semiconductor layer 508 in trench structure 520-1. In some embodiments, the opening for word line contact 514 extends in insulating structure 518 and exposes conductor layer 510 in the corresponding stair. The deposition of the conductive material may include CVD, PVD, ALD, electroplating, electroless plating, and a combination thereof.

Referring back to FIG. 6, method 600 proceeds to operation 608, in which a hole is formed extending from the lower surface of the base structure to the first contact portion. FIG. 5G illustrates a corresponding structure.

As shown in FIG. 5G, a hole 515 may be formed extending from the lower surface of base structure 504 to first contact portion 516-1. A portion of base structure 504, i.e., a portion of insulating layer 502, stop layer 524, and semiconductor layer 508 enclosed by trench structure 520-1 (if any), may be removed to form hole 515, which extends from the lower surface of base structure 504, e.g., the lower surface of insulating layer 502, to first contact portion 516-1. Hole 515 may be in contact with and exposing first contact portion 516-1. In various embodiments, the upper surface of hole 515 may be coplanar with or above the upper surface of stop layer 524 to ensure sufficient contact between first contact portion 516-1 and hole 515 (or subsequently-formed second contact portion). As shown in FIG. 5G, the lateral dimensions of a hole 515 may be sufficiently large to fully contact first contact portion 516-1 and may be sufficiently small to not laterally pass trench structure 520-1. In some embodiments, the lateral dimensions of hole 515 may be less than or equal to the lateral dimensions of trench structure 520-1 (or spacer structure 520). In some embodiments, another hole (not shown), for forming a source contact structure, may be formed in base structure 504 in the same patterning process that forms a hole 515. The patterning process may include a suitable etching process, e.g., dry etch and/or wet etch processes.

Referring back to FIG. 6, method 600 proceeds to operation 610, in which a second contact portion is formed in the hole and in contact with the first contact portion. FIG. 5H illustrates a corresponding structure.

As shown in FIG. 5H, a second contact portion 516-2 may be formed in hole 515, in contact with first contact portion 516-1. A conductive material, such as tungsten, can be deposited to fill in hole 515 and the other hole for forming the source contact structure. Any suitable film deposition method can be performed to deposit the conductive material. For example, the deposition method may include CVD, PVD, ALD, electroplating, electroless plating, or a combination thereof. In some embodiments, a source contact structure may be formed by the same deposition process that forms second contact portion 516-2. A contact structure 516, having first and second contact portions 516-1 and 516-2 in contact with each other, may be formed extending through insulating structure 518 and base structure 504 (e.g., spacer structure 520), connecting peripheral circuits of the 3D memory device. A lower surface of first contact portion 516-1 may be below the upper surface of semiconductor layer 508. The upper surface of second contact portion 516-2 may be a flat/leveled surface.

FIGS. 7A-7H illustrate a fabrication process for forming another 3D memory device, according to some embodiments of the present disclosure. FIG. 8 illustrates a flowchart

of a method **800** for forming the 3D memory device, according to some embodiments of the present disclosure. Examples of the 3D memory device depicted in FIGS. 7A-7H and **8** include the 3D memory device depicted in FIGS. 2A-2C and 3A-3C. FIGS. 7A-7H and **8** will be described together. It is understood that the operations shown in method **800** are not exhaustive and that other operations can be performed as well before, after, or between any of the illustrated operations. Further, some of the operations may be performed simultaneously, or in a different order than shown in FIG. **8**.

Referring to FIG. **8**, method **800** starts at operations **802**, in which a supporting structure opening and a spacer structure opening are simultaneously formed in a base structure, and a supporting structure and a spacer structure are formed in the supporting structure opening and the spacer structure opening respectively. FIGS. 7A-7D illustrate corresponding structures.

As shown in FIGS. 7A and 7B, at the beginning of the fabrication process, a supporting structure opening, and a spacer structure opening are simultaneously formed in a base structure **704**. In some embodiments, the supporting structure opening and the spacer structure opening are formed by the same fabrication steps/operations. The shapes and depth of the trench structure may correspond to those of the subsequently-formed supporting structure and spacer structure. Base structure **704** may include an initial semiconductor layer **708** on a stop layer **724**, which is further on an insulating layer **702**. Initial semiconductor layer **708** may include a sacrificial sublayer, which can partially be replaced by a semiconductor sublayer **708-1** for forming semiconductor layer **708**. The detailed description of initial semiconductor layer **708**, semiconductor layer **708**, stop layer **724**, and insulating layer **702** may be referred to the description of the initial semiconductor layer, semiconductor layer **108**, stop layer **124**, and insulating layer **102**, and is not repeated herein.

Base structure **704** may be formed on one side (e.g., the first side) of a substrate. The substrate can be a silicon substrate or a carrier substrate, made of any suitable materials, such as semiconductors, glass, sapphire, plastic, to name a few. In some embodiments, insulating layer **702** includes a dielectric material such as silicon oxide. In some embodiments, stop layer **724** includes a high-k dielectric material such as aluminum oxide. In some embodiments, the later formed semiconductor layer **708** includes polysilicon having a uniform doping profile. In some embodiments, insulating layer **702**, stop layer **724**, and semiconductor layer **708** are sequentially formed on the substrate by any suitable film deposition methods such as chemical vapor deposition (CVD), physical vapor deposition (PVD), atomic layer deposition (ALD), electroplating, electroless deposition, and a combination thereof. Subsequently, the substrate may be removed or thinned for forming various structures such as contact vias. In some embodiments, the substrate is removed or thinned at a suitable time of the fabrication process such that contact vias can be formed from the lower surface of base structure **704**.

The spacer structure opening may have a hole **720-1** in the peripheral region of base structure **704** (e.g., initial semiconductor layer **708**). Different from trench structure **520-1**, hole **720-1** takes up the entire area enclosed by spacer structure **720** such that the enclosed area when later be filled with a dielectric material, may be insulated from semiconductor layer **708**. In some embodiments, hole **720-1** may extend from the upper surface of semiconductor layer **708** to at least the lower surface of initial semiconductor layer **708**.

For example, the lower surface of hole **720-1** may stop on or in stop layer **724**. In some embodiments, the lower surface of initial semiconductor layer **708** stops at stop layer **724**. The depth of hole **720-1** may at least be the thickness of initial semiconductor layer **708** along the z-direction. Hole **720-1** of spacer structure **720** may be formed by any suitable patterning process such as dry etch and/or wet etch, following a photolithography process.

The supporting structure opening may have a hole **760-1** in the peripheral region of base structure **704** (e.g., initial semiconductor layer **708**). Different from trench structure **560-1**, hole **760-1** takes up the entire area enclosed by spacer structure **720** such that the enclosed area when later be filled with a material that is different from the material of initial semiconductor layer **708**, may not be etched when semiconductor layer **708** is formed. In some embodiments, hole **760-1** may extend from the upper surface of initial semiconductor layer **708** to at least the lower surface of initial semiconductor layer **708**. For example, the lower surface of hole **760-1** may stop on or in stop layer **724**. In some embodiments, the lower surface of initial semiconductor layer **708** stops at stop layer **724**. The depth of hole **760-1** may at least be the thickness of semiconductor layer **708** along the z-direction. Hole **760-1** of supporting structure **760** may be formed by the same patterning process as the that of hole **720-1** of spacer structure **720**. For example, the spacer structure opening and the supporting structure opening can be formed, in the peripheral region and the staircase region of the 3D memory device respectively and simultaneously, e.g., using the same etching process, by patterning base structure **704** (e.g., semiconductor layer **708**) using a "zero mask," which is used for patterning base structure **704** before any structure is formed thereon.

As shown in FIGS. 7C and 7D, spacer structure **720** may be formed in the spacer structure opening for forming a well structure (e.g., spacer structure **720**). A dielectric material, e.g., silicon oxide and/or TEOS, can be deposited to fill hole **720-1** of the spacer structure opening, forming spacer structure **720**. The dielectric material may be deposited by any suitable film deposition method such as CVD, PVD, ALD, and a combination thereof.

A supporting structure **760** (shown in FIGS. 7C and 7D) may be formed in the supporting structure opening for forming a well structure (e.g., supporting structure **760**). A material different from the material of semiconductor layer **708**, e.g., an insulating material such as silicon oxide and/or TEOS, can be deposited to fill hole **760-1** of the supporting structure opening, forming supporting structure **760**. The filled material may be deposited by any suitable film deposition method such as CVD, PVD, ALD, and a combination thereof. In various embodiments, spacer structure **720** and supporting structure **760** can be formed by the same deposition process or separate deposition processes.

In some embodiments, to increase yield, the spacer structure opening and the supporting structure opening can both be filled with the same material in the same deposition process. For example, as illustrated in FIGS. 7C and 7D, the spacer structure opening and the supporting structure opening can both be filled with a dielectric material such as TEOS in the same deposition process before forming a dielectric stack is formed on base structure **704**.

Referring back to FIG. **8**, method **800** proceeds to operation **804**, in which a memory stack including a core array region and a staircase region is formed on the base structure.

As illustrated in FIG. 7E, a dielectric stack, which subsequently forms the memory stack, can be formed on base structure **704** on the substrate. The dielectric stack can

include a plurality of interleaved sacrificial layers and dielectric layers. In some embodiments, the dielectric stack, having a plurality pairs of a sacrificial layer and a dielectric layer, is formed on semiconductor layer **708** and supporting structure **760**, the staircase region of which overlaps and is aligned with supporting structure **760**. The interleaved sacrificial layers and dielectric layers can be alternatively deposited on semiconductor layer **708** and supporting structure **760** to form the dielectric stack. In some embodiments, each dielectric layer includes a layer of silicon oxide, and each sacrificial layer includes a layer of silicon nitride. In some embodiments, a pad oxide layer (e.g., silicon oxide layer, not shown) is formed between semiconductor layer **708** and/or supporting structure **760**, and the dielectric stack. An insulating structure **718**, having a suitable dielectric material such as silicon oxide, can be deposited over the dielectric stack and base structure **704** at a suitable time during the fabrication process, for example, after a staircase structure is formed (will be described below), such that the dielectric stack is located in insulating structure **718**. The dielectric stack, insulating structure **718**, and the pad oxide layer (if any) can be formed by one or more thin film deposition processes including, but not limited to, CVD, PVD, ALD, or any combination thereof.

Before the formation of the contact structure, other structures, although not shown in FIGS. 7A-7H, can be formed in the 3D memory device (e.g., the dielectric stack). In some embodiments, a channel structure extending vertically through the dielectric stack, semiconductor layer **708**, and stopping at stop layer **724** is formed in the core array region of the dielectric stack. In some embodiments, to form the channel structure, a channel hole, e.g., an opening, extending vertically through the dielectric stack, and semiconductor layer **708**, is formed, and a memory film (e.g., a blocking layer, a storage layer, and a tunneling layer) and a semiconductor channel are sequentially formed along a sidewall of the channel hole. The deposition of the films and layers in the channel hole may include ALD, CVD, PVD, any other suitable processes, or any combination thereof. In some embodiments, a channel plug is formed above and in contact with the semiconductor channel. In some embodiments, fabrication processes for forming the channel hole include wet etching and/or dry etching processes, such as deep-ion reactive etching (DRIE). The etching of the channel hole continues until being stopped by stop layer **724**, due to the etching selectivity between the materials of stop layer **724** and semiconductor layer **708**, according to some embodiments.

To conductively connect semiconductor layer **708** and the channel structure, a semiconductor sublayer **708-1**, in contact with and conductively connected to the semiconductor channel, is formed in semiconductor layer **708**. In some embodiments, a lower portion of the memory film is removed such that the memory film becomes disconnected. Semiconductor sublayer **708-1**, in contact with the semiconductor channel, can be formed by replacing the sacrificial sublayer of initial semiconductor layer **708**. The formation of semiconductor sublayer **708-1** may include suitable dry etch and/or wet etch processes, CVD, PVD, ALD, and a combination thereof. An insulating spacer, dividing the memory cells into a plurality of blocks, can also be formed. The formation of the insulating spacer may include suitable dry etch and/or wet etch processes, CVD, PVD, ALD, and a combination thereof.

In some embodiments, a slit structure is formed extending vertically through the dielectric stack, stopping in semiconductor layer **708** (e.g., in 3D memory device **200**). For

example, a slit opening extends vertically through the dielectric stack, into initial semiconductor layer **708**, and exposes part of the sacrificial sublayer of initial semiconductor layer **708** may be formed. In some embodiments, fabrication processes for forming the slit opening include wet etching and/or dry etching, such as DRIE. In some embodiments, the slit opening extends further into the top portion of the sacrificial sublayer. The etching process through the dielectric stack may not stop at the top surface of the sacrificial sublayer and may continue to etch part of the sacrificial sublayer. The slit openings are formed between memory blocks **103**, as shown in FIG. 2B (e.g., for forming first slit structures) and between memory fingers **107** (e.g., for forming second slit structures) according to some embodiments. In some embodiments, the slit structure can be formed by depositing dielectrics into the slit opening using one or more thin film deposition processes, such as ALD, CVD, PVD, any other suitable processes, or any combination thereof. It is understood that although not shown, in some examples, the slit structure may be formed by depositing dielectrics (as a spacer) and conductive materials (as a contact) into the slit opening. As described above along with FIGS. 2B and 2C, the second slit structures (e.g., the slit structures between memory fingers **206**) divide supporting structure **760** into multiple sub-supporting structures, each corresponding to (e.g., overlaps and/or aligned with) a memory finger divided by the second slit structures.

In some other embodiments, a slit structure is formed extending vertically through the dielectric stack, stopping in semiconductor layer **708** or in supporting structure **760** (e.g., in 3D memory device **300**). For example, at least one slit opening (e.g., a first slit opening) extending vertically through the dielectric stack, into initial semiconductor layer **708**, and exposing part of the sacrificial sublayer of initial semiconductor layer **708** may be formed, and at least one slit opening (e.g., a second slit opening) extending vertically through the dielectric stack, into supporting structure **760**, and exposing part of the well structure of supporting structure **760** may be formed as well. In some embodiments, fabrication processes for forming the slit opening include wet etching and/or dry etching, such as DRIE. In some embodiments, the first and second slit openings extend further into the top portion of the sacrificial sublayer and the well structure of supporting structure **760**, respectively. The etching process through the dielectric stack may not stop at the top surface of the sacrificial sublayer and the well structure of supporting structure **760**, and may continue to etch part of the sacrificial sublayer and the well structure of supporting structure **760** respectively. The first slit openings are formed between memory blocks **103**, as shown in FIG. 3B (e.g., for forming first slit structures) and the second slit openings are formed between memory fingers **107** (e.g., for forming second slit structures) according to some embodiments. In some embodiments, the slit structure can be formed by depositing dielectrics into the slit opening using one or more thin film deposition processes, such as ALD, CVD, PVD, any other suitable processes, or any combination thereof. It is understood that although not shown, in some examples, the slit structure may be formed by depositing dielectrics (as a spacer) and conductive materials (as a contact) into the slit opening. As described above along with FIGS. 3B and 3C, the second slit structures (e.g., the slit structures between memory fingers **107**) does not divide supporting structures into multiple sub-supporting structures, and one memory block corresponds to (e.g., overlaps and/or aligned with) a consecutive supporting structure **560** with no sub-supporting structures in between.

A gate replacement process can be performed to replace the sacrificial layers in the dielectric stack to form a plurality of conductor layers. In some embodiments, the gate replacement process is performed after the slit structures are formed and through the slit structures. A memory stack **706**, having a plurality of interleaved conductor layers **710** and dielectric layers **712**, can be formed on semiconductor layer **708**. The gate replacement process may include a suitable isotropic etching process, CVD, PVD, ALD, and a combination thereof. The channel structures, extending through memory stack **706**, may be in contact with and conductively connected to semiconductor layer **708** through the semiconductor channel. In some embodiments, memory stack **706** may be repetitively patterned to form a staircase structure in the staircase region, which includes a plurality of stairs extending laterally (e.g., along the x/y-direction). The patterning process of memory stack **706** may include repetitive photolithography processes and recess etches (e.g., an isotropic etching process).

Referring back to FIG. **8**, method **800** proceeds to operation **806**, in which a first contact portion is formed in the well structure of the spacer structure. FIG. **7F** illustrates a corresponding structure.

As shown in FIG. **7F**, a first contact portion **716-1** may be surrounded and in contact with the well structure (e.g., hole **720-1** filled with dielectric material) of spacer structure **720**. In other words, a diameter of first contact portion **716-1** is smaller than a diameter of the well structure of spacer structure **720** in a plan view (e.g., in the x-y plane), such that first contact portion **716-1** may be insulated from semiconductor layer **708** by spacer structure **720** (e.g., by the well structure of spacer structure **720**). It is understood that first contact portion **716-1** and the well structure of spacer structure **720** may be of any suitable shapes such as oval, squared, rectangular, and circular shapes. In some embodiments, the well structure of spacer structure **720** and first contact portion **716-1** may have the same shape or different shapes in the plan view.

First contact portion **716-1** may be formed in insulating structure **718** and landed on the lower surface of the well structure of spacer structure **720**. First contact portion **716-1** may be surrounded by and in contact with the well structure of spacer structure **720**. First contact portion **716-1** is therefore isolated from semiconductor layer **708** outside of spacer structure **720**. In some embodiments, first contact portion **716-1** is formed by the same process that forms a word line contact **714**, which lands on a respective stair to form a conductive connection with conductor layer **710** in the stair. First contact portion **716-1** and word line contact **714** may each include a suitable conductive material such as tungsten. In some embodiments, the lower surface of first contact portion **716-1** does not reach the lower surface of the well structure of spacer structure **720** but is below the upper surface of semiconductor layer **708** such that the etching from the lower surface of base structure **704** can be reduced when the second contact portion is being formed. That is, the hole to form the second contact portion does not need to reach the upper surface of semiconductor layer **708** from the lower surface of base structure **704**, i.e., insulating layer **702**.

The formation of first contact portion **716-1** and word line contact **714** may include a patterning process followed by a suitable film deposition process. The patterning process may remove portions of insulating structure **718** to form openings, at desired depths, that correspond to the locations and positions of first contact portion **716-1** and word line contact **714**. In some embodiments, the opening for first contact portion **716-1** extends in insulating structure **718** and

exposes the well structure of spacer structure **720**. In some embodiments, the opening for word line contact **714** extends in insulating structure **718** and exposes conductor layer **710** in the corresponding stair. The deposition of the conductive material may include CVD, PVD, ALD, electroplating, electroless plating, and a combination thereof.

Referring back to FIG. **8**, method **800** proceeds to operation **808**, in which a hole is formed extending from the lower surface of the base structure to the first contact portion. FIG. **7G** illustrates a corresponding structure.

As shown in FIG. **7G**, a hole **715** may be formed extending from the lower surface of base structure **704** to first contact portion **716-1**. A portion of base structure **704**, i.e., a portion of insulating layer **702**, stop layer **724**, and the well structure of spacer structure **720** (if any), may be removed to form hole **715**, which extends from the lower surface of base structure **704**, e.g., the lower surface of insulating layer **702**, to first contact portion **716-1**. Hole **715** may be in contact with and exposing first contact portion **716-1**. In various embodiments, the upper surface of hole **715** may be coplanar with or above the upper surface of stop layer **724** to ensure sufficient contact between first contact portion **716** and hole **715** (or subsequently-formed second contact portion). As shown in FIG. **7G**, the lateral dimensions of a hole **715** may be sufficiently large to fully contact first contact portion **716-1** and may be sufficiently small to not laterally pass the well structure of spacer structure **720**. In some embodiments, the lateral dimensions of hole **715** may be less than or equal to the lateral dimensions of the well structure of spacer structure **720** (or spacer structure **720**). In some embodiments, another hole (not shown), for forming a source contact structure, may be formed in base structure **704** in the same patterning process that forms a hole **715**. The patterning process may include a suitable etching process, e.g., dry etch and/or wet etch processes.

Referring back to FIG. **8**, method **800** proceeds to operation **810**, in which a second contact portion is formed in the hole and in contact with the first contact portion. FIG. **7H** illustrates a corresponding structure.

As shown in FIG. **7H**, a second contact portion **716-2** may be formed in hole **715**, in contact with first contact portion **716-1**. A conductive material, such as tungsten, can be deposited to fill in hole **715** and the other hole for forming the source contact structure. Any suitable film deposition method can be performed to deposit the conductive material. For example, the deposition method may include CVD, PVD, ALD, electroplating, electroless plating, or a combination thereof. In some embodiments, a source contact structure may be formed by the same deposition process that forms second contact portion **716-2**. A contact structure **716**, having first and second contact portions **716-1** and **716-2** in contact with each other, may be formed extending through insulating structure **718** and base structure **704** (e.g., spacer structure **720**), connecting peripheral circuits of the 3D memory device. A lower surface of first contact portion **716-1** may be below the upper surface of spacer structure **720**. The upper surface of second contact portion **716-2** may be a flat/leveled surface.

According to one aspect of the present disclosure, a 3D memory device includes a memory stack, a semiconductor layer, a supporting structure, a spacer structure, and a contact structure. The memory stack includes interleaved conductive layers and dielectric layers and comprising a staircase region in a plan view. The semiconductor layer in contact with the memory stack. The supporting structure overlaps the staircase region of the memory stack and coplanar with the semiconductor layer, and the supporting structure

includes a material other than a material of the semiconductor layer. The supporting structure and the first semiconductor layer are coplanar. The spacer structure is outside the memory stack and is coplanar with the supporting structure and the semiconductor layer. The contact structure extends vertically and is surrounded by the spacer structure.

In some embodiments, the spacer structure has a trench structure surrounding part of the semiconductor layer, and the part of the semiconductor layer is in contact with contact structure and is insulated from a rest of the semiconductor layer by the spacer structure.

In some embodiments, the spacer structure has a well structure, and a shape of the well structure is different from a shape of the contact structure in the plan view.

In some embodiments, the spacer structure includes a dielectric material.

In some embodiments, the supporting structure and the spacer structure include a same dielectric material.

In some embodiments, the same dielectric material is TEOS.

In some embodiments, the 3D memory device further includes a first slit structure extending vertically and laterally and dividing the memory stack into a plurality of memory blocks.

In some embodiments, the 3D memory device further includes a second slit structure extending vertically and laterally and dividing each memory stack into a plurality of memory fingers.

In some embodiments, the second slit structure stops in the supporting structure, and each memory block overlaps with one supporting structure.

In some embodiments, each of the sub-supporting structure includes a trench structure surrounding part of the semiconductor layer.

In some embodiments, each of the sub-supporting structure includes a well structure filled with the material different than the material of the semiconductor layer.

According to one aspect of the present disclosure, a 3D memory device includes a memory stack, a semiconductor layer, a supporting structure, a spacer structure, a channel structure, and a contact structure. The memory stack includes interleaved conductive layers and dielectric layers and comprising a staircase region in a plan view. The semiconductor layer is in contact with the memory stack. The supporting structure overlaps the staircase region of the memory stack and coplanar with the semiconductor layer, and the supporting structure includes a material other than a material of the semiconductor layer. The supporting structure and the first semiconductor layer are coplanar. The spacer structure is outside the memory stack and is coplanar with the supporting structure and the semiconductor layer. The channel structure is in the core array region of the memory stack into the semiconductor layer and includes a semiconductor channel, wherein a lower portion of the semiconductor channel is in contact with the semiconductor layer. The contact structure extends vertically and is surrounded by the spacer structure.

In some embodiments, the spacer structure has a trench structure surrounding part of the semiconductor layer, and the part of the semiconductor layer is in contact with contact structure and is insulated from a rest of the semiconductor layer by the spacer structure.

In some embodiments, the spacer structure has a well structure, and a shape of the well structure is different from a shape of the contact structure in the plan view.

In some embodiments, the spacer structure includes a dielectric material.

In some embodiments, the supporting structure and the spacer structure include a same dielectric material.

In some embodiments, the same dielectric material is TEOS.

In some embodiments, the 3D memory device further includes a first slit structure extending vertically and laterally and dividing the memory stack into a plurality of memory blocks.

In some embodiments, the 3D memory device further includes a second slit structure extending vertically and laterally and dividing each memory stack into a plurality of memory fingers.

In some embodiments, the second slit structure stops in the supporting structure, and each memory block overlaps with one supporting structure.

In some embodiments, each of the sub-supporting structure includes a trench structure surrounding part of the semiconductor layer.

In some embodiments, each of the sub-supporting structure includes a well structure filled with the material different than the material of the semiconductor layer.

In some embodiments, the channel structure further includes a memory layer in contact with and surrounding the semiconductor channel, and a lower portion of the memory layer is disconnected to expose the semiconductor channel such that the semiconductor channel is in contact with the semiconductor layer.

According to still another aspect of the present disclosure, a method for forming a 3D memory device is disclosed. A semiconductor layer including a sacrificial layer is formed on a substrate. A supporting structure and a spacer structure are simultaneously formed in the semiconductor layer. The supporting structure and the spacer structure are coplanar with the semiconductor layer, and the supporting structure includes a material other than a material of the semiconductor layer. A dielectric stack including a staircase region, in contact with the semiconductor layer is formed. The staircase region overlaps with the supporting structure. A contact structure extending vertically and surrounded by the spacer structure is formed.

In some embodiments, to form the spacer structure, a portion of the semiconductor layer is removed to form a spacer structure opening extending through the semiconductor layer and the spacer structure opening is filled with a dielectric material.

In some embodiments, the spacer structure opening has a trench structure, dividing the semiconductor layer into an insulating portion and a sacrificial portion. The insulating portion of the semiconductor layer is in contact with the contact structure, and is insulated from the sacrificial portion of the semiconductor layer by the spacer structure.

In some embodiments, the spacer structure opening has a well structure, and a shape of the well structure is different from the shape of the contact structure in the plan view.

In some embodiments, at least one first slit structure and at least one second slit structure, extending vertically and laterally in the dielectric stack are formed, the at least one first slit structure divides the dielectric stack into a plurality of block regions, and the at least one second slit structure divides each block region into a plurality of finger regions.

In some embodiments, to form the supporting structure, a portion of the semiconductor layer is removed to form a supporting structure opening extending through the semiconductor layer, and the supporting structure opening is filled with the material different than the material of the semiconductor layer.

In some embodiments, a depth of the part of the supporting structure in contact with the first semiconductor layer is greater than a depth of the remainder of the supporting structure.

In some embodiments, to form the second slit structure, a second slit structure opening extending through the dielectric stack stopping in the supporting structure is formed.

In some embodiments, to form the second slit structure, a second slit structure opening extending through the dielectric stack stopping in the semiconductor layer is formed. The second slit structure divides the supporting structure into a plurality of sub-supporting structures.

In some embodiments, the second semiconductor structure further includes a source contact in contact with the second semiconductor layer.

In some embodiments, each sub-supporting structure opening has a trench structure, dividing the semiconductor layer into a supporting portion and a sacrificial portion. The supporting portion of the semiconductor layer overlaps the staircase region of the dielectric stack.

In some embodiments, the sacrificial layer of the sacrificial portion is replaced with a semiconductor sublayer.

In some embodiments, each sub-supporting structure opening has a well structure.

In some embodiments, the supporting structure and the spacer structure includes a same dielectric material.

In some embodiments, the same dielectric material is TEOS.

The foregoing description of the specific embodiments will so reveal the general nature of the present disclosure that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

Embodiments of the present disclosure have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present disclosure as contemplated by the inventor(s), and thus, are not intended to limit the present disclosure and the appended claims in any way.

The breadth and scope of the present disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A three-dimensional (3D) memory device, comprising:
a memory stack comprising interleaved conductive layers and dielectric layers and comprising a staircase region in a plan view;
a semiconductor layer in contact with the memory stack;

a supporting structure overlapping and arranged within the staircase region of the memory stack to be aligned with the memory stack in a vertical direction of the plan view; and

a source contact structure at a side of the semiconductor layer opposite to the memory stack and in contact with the semiconductor layer,

wherein:

the supporting structure comprises a material other than a material of the semiconductor layer;

a spacer structure is arranged outside the memory stack; in a lateral direction perpendicular to the vertical direction, the supporting structure is sandwiched within the semiconductor layer without extending to a core array region adjacent to the staircase region;

a contact structure extending vertically and surrounded by the spacer structure;

a stop layer extends, at the side of the semiconductor layer opposite to the memory stack, in the lateral direction, and the supporting structure and the spacer structure terminate on the stop layer; and

the source contact structure penetrates the stop layer to electrically couple with a channel structure through the semiconductor layer.

2. The 3D memory device of claim 1, wherein the spacer structure has a trench structure surrounding part of the semiconductor layer, wherein the part of the semiconductor layer is in contact with the contact structure and is insulated from a rest of the semiconductor layer by the spacer structure.

3. The 3D memory device of claim 1, wherein the spacer structure has a well structure, wherein a shape of the well structure is different from a shape of the contact structure in the plan view.

4. The 3D memory device of claim 1, wherein the spacer structure comprises a dielectric material.

5. The 3D memory device of claim 1, wherein the supporting structure and the spacer structure comprise a same dielectric material.

6. The 3D memory device of claim 5, wherein the same dielectric material is tetraethyl orthosilicate (TEOS).

7. The 3D memory device of claim 1, further comprising a first slit structure extending vertically and laterally and dividing the memory stack into a plurality of memory blocks.

8. The 3D memory device of claim 7, further comprising a second slit structure extending vertically and laterally and dividing each memory stack into a plurality of memory fingers.

9. The 3D memory device of claim 8, wherein the second slit structure stops in the supporting structure, wherein each memory block overlaps with a respective supporting structure.

10. The 3D memory device of claim 8, wherein the second slit structure extends vertically into the semiconductor layer and is configured to divide the supporting structure into a plurality of sub-supporting structures, wherein each memory finger overlaps with one of the sub-supporting structures.

11. The 3D memory device of claim 10, wherein each of the sub-supporting structures comprises a trench structure surrounding part of the semiconductor layer.

12. The 3D memory device of claim 10, wherein each of the sub-supporting structures comprises a well structure filled with the material different than the material of the semiconductor layer.

13. A three-dimensional (3D) memory device, comprising:

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a memory stack comprising interleaved conductive layers and dielectric layers and having a core array region and a staircase region in a plan view;

a semiconductor layer in contact with the memory stack;

a supporting structure overlapping and arranged within the staircase region of the memory stack to be aligned with the staircase region in a vertical direction of the plan view, wherein:

the supporting structure comprises a material other than a material of the semiconductor layer, and an upper surface of the supporting structure is flush with an upper surface of the semiconductor layer; and

in a lateral direction perpendicular to the vertical direction, the supporting structure is sandwiched within the semiconductor layer;

a spacer structure outside the memory stack;

a source contact structure at a side of the semiconductor layer opposite to the memory stack and in contact with the semiconductor layer;

a channel structure in the core array region of the memory stack and into the semiconductor layer, comprising a semiconductor channel, wherein a lower portion of the semiconductor channel is surrounded by and in direct contact with the semiconductor layer; and

a contact structure extending vertically and surrounded by the spacer structure,

wherein:

a stop layer extends, at the side of the semiconductor layer opposite to the memory stack, in the lateral direction, and the supporting structure and the spacer structure terminate on the stop layer; and

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the source contact structure penetrates the stop layer to electrically couple with the channel structure through the semiconductor layer.

14. The 3D memory device of claim 13, wherein the spacer structure has a trench structure surrounding part of the semiconductor layer, wherein the part of the semiconductor layer is in contact with the contact structure and is insulated from a rest of the semiconductor layer by the spacer structure.

15. The 3D memory device of claim 13, wherein the spacer structure has a well structure, wherein a shape of the well structure is different from a shape of the contact structure in the plan view.

16. The 3D memory device of claim 13, further comprising a first slit structure extending vertically and laterally and dividing the memory stack into a plurality of memory blocks.

17. The 3D memory device of claim 16, further comprising a second slit structure extending vertically and laterally and dividing each memory stack into a plurality of memory fingers.

18. The 3D memory device of claim 17, wherein the second slit structure stops in the supporting structure, wherein each memory block overlaps with a respective supporting structure.

19. The 3D memory device of claim 17, wherein the second slit structure extends vertically into the semiconductor layer and is configured to divide the supporting structure into a plurality of sub-supporting structures, wherein each memory finger overlaps with one sub-supporting structure.

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